# COLLEGE OF ENGINEERING

## ADMINISTRATION

W. Kent Fuchs, dean

David Gries, associate dean for undergraduate programs

Michael Spencer, associate dean for research, graduate studies, and professional education

Zellman Warhaft, associate dean for diversity

Deborah Cox, assistant dean for strategic planning, assessment, and new initiatives

Betsy East, assistant dean for student services

Cathy Long, assistant dean for administration

Marsha Pickens, assistant dean for alumni affairs and development

## FACILITIES AND SPECIAL PROGRAMS

Most of the academic units of the College of Engineering are on the Joseph N. Pew, Jr. Engineering Quadrangle. The School of Applied and Engineering Physics is located in Clark Hall on the College of Arts and Sciences campus, and the Department of Biological and Environmental Engineering is in Riley-Robb Hall on the campus of the New York State College of Agriculture and Life Sciences.

Special university and college facilities augment the laboratories operated by the various engineering schools and departments, and special centers and programs contribute to opportunities for study and research.

Cornell programs and centers of interest in engineering include the following:

*Center for Applied Mathematics.* This cross-disciplinary center administers a graduate program.

*Center for Nanoscale Systems in Information Technologies.* The mission of this National Science Foundation Nanoscience and Technology Center is to explore new methods for creating nanoscale devices for use in information technologies. The facilities for this center are distributed between Clark Hall and the Engineering Quadrangle and especially in the new Duffield Hall.

*Center for Radiophysics and Space Research.* This interdisciplinary unit facilitates research in astronomy and the space sciences.

*Center for Theory and Simulation in Science and Engineering.* A supercomputer facility used for advanced research in engineering and the physical and biological sciences.

*Cornell High Energy Synchrotron Source (CHESS).* A high-energy synchrotron radiation laboratory operated in conjunction with the university's high-energy storage ring. Current research programs at CHESS are in areas of structural biology, chemistry, materials science, and physics.

*Cornell Nanoscale Science and Technology Facility* (part of the National Science Foundation–funded National Nanofabrication Users Network). This center provides equipment and services for research in the science, engineering, and technology of nanometer-scale structures for electronic, chemical, physical, and biological applications.

*Cornell Waste Management Institute.* This research, teaching, and extension program within the Center for Environmental Research addresses the environmental, technical, and economic issues associated with solid waste; one facility sponsored by the institute is the Combustion Simulation Laboratory in the Sibley School of Mechanical and Aerospace Engineering.

*Institute for the Study of the Continents.* This interdisciplinary organization promotes research on the structure, composition, and evolution of the continents.

*W. M. Keck Foundation in Nanobiotechnology.* Facilities of this program include tools for nanoscale diagnostics of biomaterials.

*Laboratory of Plasma Studies.* A center for research in plasma physics.

*Cornell Center for Materials Research.* An interdisciplinary facility, with substantial support from the National Science Foundation, providing sophisticated scientific measurement and characterization equipment for materials research.

*National Astronomy and Ionosphere Center.* The world's largest radio-radar telescope facility, operated by Cornell in Arecibo, Puerto Rico.

*Multidisciplinary Center for Earthquake Engineering Research.* A facility established by the National Science Foundation and a group of universities to study response and design of structures in earthquake environments.

*Nanobiotechnology Center.* The mission of this National Science Foundation Science and Technology Center is to develop nanoscale technologies and science applied to the life sciences. The facilities of this center are distributed between Clark Hall, Kimball Hall, and the Biotechnology Center.

*National Institutes of Health/National Science Foundation Developmental Resource in Biophysical Imaging and Optoelectronics.* This resource develops novel measurement and optical instrumentation for solving biophysical problems.

*Network for Earthquake Engineering Simulation (NEES).* A system of nationwide experimental facilities linked by high-performance Internet for laboratory and computational simulation of structures under earthquake loads.

*Power Systems Engineering Research Center.* A National Science Foundation cooperative center between university and industry in which research is centered on power systems and infrastructure networks.

*Program of Computer Graphics.* This interdisciplinary research center operates one of the most advanced computer-graphics laboratories in the United States.

*Program on Science, Technology, and Society.* This cross-disciplinary unit sponsors courses and promotes research on the interaction of science, technology, and society.

The programs listed on this page are sponsored by College of Engineering units, and several are industry affiliated.

## DEGREE PROGRAMS

Cornell programs in engineering and applied science lead to the degrees of bachelor of science (B.S.), master of engineering (with field designation) (M.Eng.), master of science (M.S.), and doctor of philosophy (Ph.D.).

General academic information concerning the B.S. degree is given below in the section "Undergraduate Study." The student pursues the degree in one of 13 majors. The majors are described in the section "Engineering Majors."

Many students stay a fifth year in the College of Engineering to pursue a professional degree, the Master of Engineering (M.Eng.) degree. Joint enrollment in the B.S. and M.Eng. degrees is possible for students in their last semester who lack only 1 to 8 credits for the B.S.

M.Eng. degrees are given in most of the major areas. In addition, the following M.Eng. degrees are given: Aerospace Engineering, Biomedical Engineering, Electrical Engineering, Engineering Mechanics, Nuclear Engineering, Operations Research and Industrial Engineering, and Systems Engineering. For full details on M.Eng. degrees, see the section "Master of Engineering Degree Programs."

Programs leading to the M.S. and Ph.D. degrees are administered by the Graduate School. They are described in the *Announcement of the Graduate School* and the special announcement *Graduate Study in Engineering and Applied Science.*

## UNDERGRADUATE STUDY

Students in the College of Engineering spend most of their first two years of undergraduate studies in the Common Curriculum, which is administered by the College Curriculum Governing Board (CCGB) through the associate dean for undergraduate programs and Engineering Advising. At the end of their third semester, they affiliate with one of these majors: *

Biological Engineering (BE)†

Chemical Engineering (ChemE)

Civil Engineering (CE)

Computer Science (CS)

Electrical and Computer Engineering (ECE)

Engineering Physics (EP)

Environmental Engineering (EnvE) (pending)

Geological Sciences (GeoS)—with options in Geoscience, Atmospheric Science, and Science of Earth Systems

Independent Major (IM)

Information Science, Systems, and Technology (ISST)—with options in Information Science and Management Science

Materials Science and Engineering (MSE)

Mechanical Engineering (ME)

Operations Research and Engineering (ORE)

Criteria for affiliation with the majors are described in the section "Affiliation with a Major." The majors are described in the section "Undergraduate Engineering Majors."

Most of the majors have a corresponding minor or option, in which the student can pursue a secondary interest. In addition, there are minors in Applied Mathematics, Biomedical Engineering, Civil Infrastructure, Engineering Management, Engineering Statistics, Industrial Systems and Information Technology, and Information Science. There is one option, in Bioengineering. See the main section, "Engineering Minors and Options."

*The majors Biological Engineering, Chemical Engineering, Civil Engineering, Electrical and Computer Engineering (under the title Electrical Engineering), Engineering Physics, Materials Science and Engineering, Mechanical Engineering, and Operations Research and Engineering are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

†To major in Biological Engineering, students normally enroll in the College of Agriculture and Life Sciences for the first three years and jointly in that college and the College of Engineering for the final year. However, students initially enrolled in the College of Engineering may affiliate with the Biological Engineering major and complete the degree solely within Engineering.

There is no undergraduate major in nuclear science and engineering. Students who intend to enter graduate programs in this area are encouraged to begin specialization at the undergraduate level. This may be done by choice of electives within the major (e.g., Engineering Physics, Materials Science and Engineering, Civil Engineering, Chemical Engineering, and the Independent Major). Contact one of the faculty members in the graduate Field of Nuclear Science and Engineering who are most directly concerned with the curriculum, including K. B. Cady, D. A. Hammer, R. W. Kay, and V. O. Kostroun.

## Graduation Requirements

To receive the bachelor of science degree, students must meet the requirements of the Common Curriculum (outlined below) as set forth by the College of Engineering, including the requirements of their chosen major, as established by the school or department that administers the major. (Further explanation of the revised Common Curriculum and major flow charts are provided in the 2004–2005 edition of the *Engineering Undergraduate Handbook.*)

| *Course Category* | *Credits* |
|---|---|
| 1. Mathematics | 16 |
| 2. Physics (major-specific) | 8–12 |
| 3. Chemistry (major-specific) | 4–8 |
| 4. First-year writing seminar | 6 |
| 5. Technical writing | 3 |
| 6. Computer programming | 4 |
| 7. Introduction to engineering (ENGRI) | 3 |
| 8. Two engineering distributions (ENGRD) | 6 |
| 9. Liberal studies distribution (6 courses min.) | ≥ 18 |
| 10. Adviser-approved electives | 6 |
| 11. Major program | |
| a. Major-required courses | ≥ 30 |
| b. Major-approved electives | 9 |
| c. Courses outside the major | 9 |
| 12. Two terms of physical education in the freshman year and demonstration of proficiency in swimming (university requirement) | |

From 123 to 133 credits are required for graduation, depending on the major (see the section "Engineering Majors").

### Mathematics

The normal program in mathematics includes MATH 191 (or 190), 192, 293 or 294 (depending on the major), and a major-specific math course. At least C- must be attained in these courses; if not, the course must be repeated immediately before the next course in the sequence is taken. Failure to achieve at least C- the second time will generally result in withdrawal from the Engineering College. Courses that are taken a second time to meet this requirement do not yield additional credit toward a degree.

### Physics

The normal program in physics includes PHYS 112, 213, and 214 or the corresponding honors courses (PHYS 116, 217, and 218). Engineering students must attain at least C- in each math prerequisite of a physics course before taking the physics course (e.g., C- in MATH 191 before taking PHYS 112 and C- in MATH 192 before taking PHYS 213). Students in the majors BE, ChemE, CE, CS, GeoS (geoscience and SES options), ISST, and ORE may substitute CHEM 208 for PHYS 214.

### Chemistry

CHEM 211 or 207 is required.

CHEM 211 is designed for students who do not intend further study in chemistry. Typically, CHEM 211 is taken during the freshman year, but students who wish to complete the physics program (PHYS 112, 213, and 214) first may postpone CHEM 211 until the sophomore year.

Students intending to affiliate with the following majors usually take CHEM 211: Engineering Physics; Computer Science; Electrical and Computer Engineering; Information Science, Systems, and Technology; Materials Science and Engineering; Mechanical Engineering; and Operations Research and Engineering. Students considering Chemical Engineering must take CHEM 207 in the fall of their freshman year and CHEM 208 in the spring term. Students considering Environmental Engineering, the science-of-earth-systems option in Geological Sciences, or a health-related career such as medicine should take the CHEM 207–208 sequence.

### First-Year Writing Seminars

Each semester of their freshman year, students choose a first-year writing seminar from among more than one hundred courses offered by over thirty different departments in the humanities, social sciences, and expressive arts. These courses offer the student practice in writing English prose. They also assure beginning students the benefits of a small class.

### Technical Writing

Students can fulfill the upper-level technical-writing requirement using one of the six alternatives below. See www.engineering.cornell.edu/ECP/index.htm for more information about these alternatives.

1. ENGRC 350 or ENGRC 335, taught by the Engineering Communications Program
2. The Writing-Intensive Co-op—an opportunity to combine work and academics. Some Co-op students do a significant amount of writing on the job; under certain circumstances, this writing might satisfy the college's technical-writing requirement. More information is available at www.engineering.cornell.edu/ECP/Writing-IntensiveCoop.htm.
3. An officially designated Writing-Intensive (W-I) engineering course:
   - ENGRD/AEP 264
   - CHEME 432
   - MSE 403 & 404 (both)
   - MSE 405 & 406 (both)
   - M&AE 427
   - BEE 450 with co-registration in BEE 493
   - BEE 473 with co-registration in BEE 493
   - BEE 489
4. ENGRC 302, a 1-credit attachment to an engineering course that is not one of the officially designated W-I courses (see #3 above). An instructor may wish to extend the writing done in his or her course for a given semester so that it will fulfill the technical-writing requirement. With the approval of the CCGB's Subcommittee on Technical Writing, the instructor may have students co-register in ENGRC 302. May be taken more than once, with different courses. By permission of engineering instructor.
5. COMM 260, 263, or 352, taught by the Department of Communication (in the College of Agriculture and Life Sciences)
6. Petition. Occasionally, a student will be doing a significant amount and variety of technical writing elsewhere in the Engineering College. It may be appropriate to petition the CCGB's Subcommittee on Technical Writing for permission to use this upcoming writing (not past writing) to meet the technical-writing requirement.

### Computer Programming

COM S 100, Introduction to Computer Programming, is normally taken in the freshman year to fulfill the computer programming requirement.

Before taking COM S 100, some students take COM S 099, Fundamental Programming Concepts, offered in the fall and summer. This 2-credit S-U course is meant for students with virtually no programming experience; students with previous programming experience may not take it. Basic programming concepts and problem analysis are studied. COM S 099 may not be used as credit toward graduation.

### Introduction to Engineering Course

An introduction to engineering course (designated ENGRI) must be taken during the freshman year. This course will introduce students to the engineering process and provide a substantive experience in an open-ended problem-solving context. See the Introduction to Engineering course listing for current course offerings.

### Engineering Distribution

Two engineering distribution (ENGRD) courses (6–8 credits) must be selected from two different categories listed below. A student may use any one of the possible substitutions described.

1. *Scientific computing*

   ENGRD 211, Computers and Programming

   ENGRD 241, Engineering Computation

   ENGRD 321, Numerical Methods in Computational Molecular Biology

   ENGRD 322, Introduction to Scientific Computation

2. *Materials science*

   ENGRD 261, Introduction to Mechanical Properties of Materials: From Nanodevices to Superstructures

   ENGRD 262, Electronic Materials for the Information Age

3. *Mechanics*

   ENGRD 202, Mechanics of Solids

   ENGRD 203, Dynamics

   Majors in Engineering Physics may substitute A&EP 333 for ENGRD 203.

4. *Probability and statistics*

   ENGRD 270, Basic Engineering Probability and Statistics

   Majors in Electrical and Computer Engineering may substitute ECE 310 for ENGRD 270. Majors in Engineering Physics may substitute ECE 310 or MATH 471 for ENGRD 270. Majors in Civil Engineering and Biological Engineering may substitute CEE 304 for ENGRD 270.

5. *Electrical sciences*

   ENGRD 210, Introduction to Circuits for Electrical and Computer Engineers

   ENGRD 230, Introduction to Digital Logic Design

   ENGRD 264, Computer-Instrumentation Design

6. *Thermodynamics and energy balances*

   ENGRD 219, Mass and Energy Balances

   ENGRD 221, Thermodynamics

7. *Earth and life sciences*

   ENGRD 201, Introduction to the Physics and Chemistry of the Earth

   ENGRD 251, Engineering for a Sustainable Society

   ENGRD 260, Principles of Biological Engineering

8. *Biology and chemistry*

   ENGRD 252/A&EP 252, The Physics of Life

   BIO G 101 and 103, Biological Sciences, Lecture and Laboratory

   BIO G 105, Introductory Biology

   BIO G 107, General Biology (summer only)

   CHEM 389, Physical Chemistry I

Some majors require a specific engineering distribution course as a prerequisite for the upperclass course sequence. These requirements are as follows:

Biological Engineering: ENGRD 202

Chemical Engineering: ENGRD 219

Civil Engineering: ENGRD 202

Computer Science: ENGRD 211 (co-enrollment in COM S 212 strongly recommended)

Electrical and Computer Engineering (pending): ENGRD 230

Environmental Engineering: ENGRD 202

Geological Sciences: ENGRD 201

Information Science, Systems, and Technology: ENGRD 270

Materials Science and Engineering: ENGRD 261

Mechanical Engineering: ENGRD 202

Operations Research and Engineering: ENGRD 270

Some majors require additional distribution courses after the student affiliates.

### Liberal Studies Distribution

The following liberal studies distribution requirements begin with the class entering in 2003. Students who entered before that may choose to use the new requirements.

Global and diverse societies require that engineers have an awareness of historical patterns, an appreciation for different cultures, professional ethics, the ability to work in multifaceted groups, and superior communications skills. Cornell has a rich curriculum in the humanities, arts, and social sciences, enabling every engineering student to obtain a true liberal education. At least six courses (totaling at least 18 credits) are required, and they should be chosen with as much care and foresight as courses from technical areas.

- The six courses must be chosen from at least three of the following six groups.
- At least two courses must be from the first three groups (CA, HA, LA).
- At least two of the six courses must be at the 200 level or higher.

The Engineering Advising web site (www.engineering.cornell.edu/studentServices/advising.cfm) contains a complete listing of acceptable courses in each group. A list of courses is also available in Engineering Advising, 167 Olin Hall.

**Group 1. Cultural Analysis (CA)**

Courses in this area study human life in particular cultural contexts through interpretive analysis of individual behavior, discourse, and social practice. Topics include belief systems (science, medicine, religion), expressive arts and symbolic behavior (visual arts, performance, poetry, myth, narrative, ritual), identity (nationality, race, ethnicity, gender, sexuality), social groups and institutions (family, market, community), and power and politics (states, colonialism, inequality).

**Group 2. Historical Analysis (HA)**

Courses in this group interpret continuities and changes—political, social, economic, diplomatic, religious, intellectual, artistic, scientific—through time. The focus may be on groups of people, dominant or subaltern, a specific country or region, an event, a process, or a time period.

**Group 3. Literature and the Arts (LA)**

Offerings in this area explore literature and the arts in two different but related ways. Some courses focus on the critical study of artworks and on their history, aesthetics, and theory. These courses develop skills of reading, observing, and hearing and encourage reflection on such experiences; many investigate the interplay among individual achievement, artistic tradition, and historical context. Other courses are devoted to the production and performance of artworks (in creative writing, performing arts, and media such as film and video). These courses emphasize the interaction among technical mastery, cognitive knowledge, and creative imagination.

**Group 4. Knowledge, Cognition, and Moral Reasoning (KCM)**

Offerings in this area investigate the bases of human knowledge in its broadest sense, ranging from cognitive faculties shared by humans and animals such as perception, to abstract reasoning, to the ability to form and justify moral judgments. Courses investigating the sources, structure, and limits of cognition may use the methodologies of science, cognitive psychology, linguistics, or philosophy. Courses focusing on moral reasoning explore ways of reflecting on ethical questions that concern the nature of justice, the good life, or human values in general.

**Group 5. Social and Behavioral Analysis (SBA)**

Courses in this area examine human life in its social context through the use of social-scientific methods, often including hypothesis testing, scientific sampling techniques, and statistical analysis. Topics studied range from the thoughts, feelings, beliefs, and attitudes of individuals to interpersonal relations between individuals (e.g., in friendship, love, conflict) to larger social organizations (e.g., the family, society, religious or educational or civic institutions, the economy, government) to the relationships and conflicts among groups or individuals (e.g., discrimination, inequality, prejudice, stigmas, conflict resolution).

**Group 6. Foreign Languages (not literature courses)**

Courses in this area teach language skills, inclusive of reading, writing, listening, and spoken non-English languages, at beginning to advanced levels.

#### Electives

- **Adviser-approved electives:** 6 credits required (approved by the academic adviser). Because these courses should help develop and broaden the skills of the engineer, advisers generally accept the following as approved electives:

1. One introduction to engineering course (ENGRI)
2. Engineering distribution courses
3. Courses stressing written or oral communication
4. Upper-level engineering courses
5. Advanced courses in mathematics
6. Rigorous courses in the biological and physical sciences
7. Courses in business, economics, or language (when they serve the student's educational and academic objectives)
8. Courses that expand the major or another part of the curriculum (Note: No ROTC courses may be used as approved electives unless they are co-listed by an academic department.)

- **Major-approved electives:** 9 credits (approved by the major and faculty advisers in the major). Refer to the major curricula for descriptions of courses in this category.
- **Outside-the-major electives:** 9 credits of courses outside the major to ensure breadth of engineering studies

#### Social Issues of Technology

It is important for engineers to realize the social and ethical implications of their work. Consequently, in selecting their liberal studies distribution courses and approved electives, students are urged to consider courses listed in the "Science and Technology Studies" undergraduate area of concentration (see "Interdisciplinary Centers and Programs" section). These courses may provide students with important perspectives on their studies and their future careers.

### Engineering Advising

Entering freshmen are assigned a faculty adviser (who may or may not be in their intended major), who remains their adviser until affiliation with a major (normally during the fourth semester). The students are also under the administration of Engineering Advising, which implements the academic policies of the College Curriculum Governing Board. Engineering Advising serves as the primary resource center for undergraduate students in the college, offering general advising and counseling. Also located in Olin Hall are the LIFE Program, Minority Programs, and Women's Programs, which are primary resources for counseling, support, tutoring, and networking opportunities.

### Freshman-Year Requirements

During the freshman year, engineering students are expected to complete (or receive credit for) the following core requirements:

- MATH 191 (or 190) and MATH 192
- Two of: CHEM 211, 207, 208, PHYS 112, 213, 214*
- COM S 100
- Two first-year writing seminars
- One introduction to engineering (ENGRI) course
- Two physical education courses

*Students with an interest in pre-med (or other health-related careers), Chemical Engineering, Environmental Engineering, or the science-of-earth-systems option in Geological Sciences should enroll in the CHEM 207–208 sequence during their freshman year.

### Affiliation with a Major

Students must apply for affiliation with a major during the first term of their sophomore year, although earlier affiliation may be granted at the discretion of the major. This is done by visiting the undergraduate major office and completing the Application for Major Affiliation form. To affiliate, students must 1) make good progress toward completing required courses in the common curriculum, 2) have a GPA ≥ 2.0, and 3) have satisfied the major's course and grade requirements as specified below:

(Majors may impose alternative affiliation requirements for students applying for affiliation later than the first semester of the sophomore year.)

| *Major* | *Courses and Minimum Grade Requirements* |
|---|---|
| Biological Engineering | At most one grade below C- in math and science courses and BEE 151 or its equivalent |
| Chemical Engineering | At most one grade below C- in chemistry, math, physics, and chemical engineering courses. GPA ≥ 2.2 in math, science, and engineering courses |
| Civil Engineering | GPA ≥ 2.0 in engineering and science courses. At least C- in ENGRD 202 (or CHEM 208, for students who do not take ENGRD 202 before affiliation) |
| Computer Science | At least C in completed COM S and math courses. GPA ≥ 2.7 in COM S 211, 212, 280. GPA ≥ 2.7 in MATH 192/293. Visit the CS undergraduate office or the CS undergraduate web site to learn about alternative criteria for affiliation. |
| Electrical and Computer Engineering | At least C+ in MATH 293, PHYS 213, and either ECE/ENGRD 210, ECE 220, or ENGRD 230. These courses must be taken for 4 credits. GPA ≥ 2.5 in (if completed): MATH 192, 293, 294, PHYS 213, ENGRD 211, 230, ECE/ENGRD 210, ECE 220. |
| Engineering Physics | At least B- in required math and physics courses |
| Environmental Engineering | GPA ≥ 2.0 in engineering and science courses. At least C- in ENGRD 202 or CHEM 257. |
| Geological Science | Good academic standing in the college |
| Independent Major | GPA ≥ 2.0 |
| Information Science Systems, and Technology | At least C in two of MATH 293, COM S 211, ORIE 270. GPA ≥ 2.3 in completed required courses, which must be taken at Cornell |
| Materials Science and Engineering | At least C- in physics and chemistry courses. At least C in ENGRD 261 or ENGRD 262 |
| Mechanical Engineering | At least C- in math and science courses and in ENGRD 202 |
| Operations Research and Engineering | At least C- in MATH 191, 192, ENGRD 270. GPA ≥ 2.0 in math, science, and engineering courses (both overall and in the term immediately before affiliation) |

Students must be affiliated or conditionally affiliated with a major by the end of their fourth semester or they will be withdrawn from the College of Engineering, unless allowed to participate in a terminal semester.

## SPECIAL PROGRAMS

### Dual-Degree Program

The dual-degree program, intended for superior students, allows both a bachelor of science and either a bachelor of arts (B.A.) or bachelor of fine arts (B.F.A.) degree to be earned in about five years. Students registered in the College of Engineering, the College of Arts and Sciences, or the College of Architecture, Art, and Planning may apply and, after acceptance of their application, begin the dual-degree program in their second or third year. For information, contact the appropriate coordinators of dual-degree programs at 55 Goldwin Smith Hall (for Arts and Sciences), B-1 West Sibley (for Architecture, Art, and Planning), and Engineering Advising, 167 Olin Hall.

### Double Major in Engineering

The double-major option, which makes it possible to develop expertise in two allied engineering majors, generally requires at least one semester beyond the usual four years. Students affiliate with one major following normal procedures and then petition to enter a second major before the end of their junior year. All requirements of both majors must be satisfied. Further information is available from Engineering Advising, 167 Olin Hall, and the individual major offices.

## Independent Major

Students whose educational objectives cannot be met by one of the regular majors may affiliate with the independent major. Often, the desired curriculum is in an interdisciplinary area.

This major consists of an engineering major (≥ 32 credits), which may be any subject areas offered by the schools or departments of the college, and an educationally related minor (≥ 16 credits), which may be in a second engineering subject area or in a logically connected nonengineering area. The combination must form an engineering education in scope and substance and should include engineering design and synthesis as well as engineering sciences. See the discussion of this major in the section "Undergraduate Engineering Majors."

## Engineering Minors and Options

Most of the majors have a corresponding minor, requiring six courses (18 credits), in which the student can pursue a secondary interest. Besides those minors, there are minors in Applied Mathematics, Biomedical Engineering, Civil Infrastructure, Engineering Management, Engineering Statistics, Industrial Systems and Information Technology, and Information Science. There is also the Bioengineering option, which requires only four courses (12 credits) plus a seminar. See the section "Engineering Minors and Options."

## Department of Biomedical Engineering

270 Olin Hall

The charge of the new Department of Biomedical Engineering (BME) is to bridge engineering, biology, and medicine. Students are educated to convert basic discoveries in biology and medicine into medically useful devices and therapies to improve human health. Biomedical engineers also contribute to biological discovery. The 30 faculty in the Biomedical Engineering graduate field represent 12 departments and six colleges (including Weill Medical College). The BME field offers research opportunities in biomedical mechanics; biomaterials; drug delivery, design, production, and metabolism; biomedical instrumentation and diagnostics; and system biology.

The Department of BME administers the undergraduate minor in Biomedical Engineering, the Biomedical Engineering graduate field, the M.S./Ph.D. degree programs, and the M.Eng. (BME) degree.

## Engineering Communications Program

424 Hollister, 255-8558, www.engineering.cornell.edu/ECP

The Engineering Communications Program (ECP), created in 1987 at the urging of the College of Engineering faculty and employers of Cornell engineers, provides instruction in technical writing, oral presentation, and the use of graphics in both. The ECP is a recipient of the Engineering Dean's Prize in Excellence and Innovation in Teaching.

ECP courses give students experience with the difficult task of explaining technical information to audiences that have various levels of technical expertise. Students improve their writing style, become more comfortable with and effective at oral presentation, use standard forms and formats for presenting technical information, do library and Internet research on engineering topics, and study real engineering situations in which ethics may have been breached.

Enrollment in ECP courses is 20 students per section; like writing seminars elsewhere at Cornell, those taught by the ECP are discussion classes. Students' work receives abundant written comments, and conferences are frequent.

ECP members are available to consult with the faculty teaching writing-intensive technical courses and anyone else interested in including writing in their courses. They oversee the communications component of the Writing-Intensive Co-op and occasionally give talks to alumni and student groups.

## Engineering Diversity Office

146 Olin Hall, 255-0735

The Engineering Diversity Office (EDO) operates programs at all levels to facilitate the recruitment and retention of women and minority students in Engineering. EDO acts as a catalyst for the support, career placement, graduate school preparation, and overall success of women and minority students.

EDO participates in a university-wide pre-freshman summer program. EDO also provides developmental and specialized instruction each semester in subjects such as math, computer science, and English composition. Field trips and recreational activities provide opportunities for getting a better understanding of how to navigate and adapt to the college. Seminars, lectures, and workshops provide a wide range of topics that are relevant to academic and extracurricular life in the university setting.

In September and April, EDO sponsors a networking event that allows company representatives from all over the United States to meet students from historically underrepresented populations. Summer internships and permanent jobs frequently result from this event.

## Learning Initiatives for Future Engineers

167 Olin Hall, 255-9622, www.engineering.cornell.edu/studentServices/irs/

The office of Learning Initiatives for Future Engineers, or LIFE, offers programs designed to enhance the undergraduate academic experience through peer education, cooperative learning, and research opportunities.

LIFE's *Academic Excellence Workshops* (AEWs) are taken in conjunction with core engineering courses in math, computer science, and chemistry. The 1-credit AEWs are weekly two-hour cooperative learning sessions. Designed to enhance student understanding, they feature peer-facilitated group work on problems at or above the level of course material.

LIFE's *Undergraduate Research* program provides opportunities for students to obtain hands-on research experience with a faculty mentor. Students and faculty may apply for funding to cover student stipend and expense costs.

Through LIFE's *Tutors-on-Call* program, peer tutors are available free of charge to provide one-on-one tutoring assistance for many first- and second-year core engineering courses.

## Engineering Cooperative Education and Career Services

201 Carpenter Hall, 255-5006, www.engineering.cornell.edu/careerservices/ and www.engineering.cornell.edu/coop/swf/index.htm

This office assists engineering students (freshmen through Ph.D.) in career development and job search issues and administers the Engineering Cooperative Education Program. Individual advising and group seminars are available, and more than 200 national employers typically visit the office annually to recruit technical students and graduates; additional job opportunities are posted electronically. Both undergraduate and graduate students can use these resources to pursue permanent, summer, or co-op employment, but students seeking co-op opportunities must meet specific requirements.

The Engineering Cooperative Education Program (Co-op) provides an opportunity for students to gain practical experience in industry and other engineering-related enterprises before they graduate. By supplementing course work with carefully monitored, paid jobs, co-op students are able to explore their own interests and acquire a better understanding of engineering as a profession—and still graduate in four years.

To be eligible, a student must have been enrolled at Cornell for four semesters, with a GPA ≥ 2.7. (Students in Computer Science and Biological and Environmental Engineering are eligible, even though they may not be registered in the College of Engineering.) Applicants interview with participating employers. Students who receive offers and join the program usually take their fifth-term course work at Cornell during the summer after their sophomore year and begin the first co-op work period the following fall. They return to Cornell to complete the sixth semester with their classmates, complete a second work period with the same employer the following summer, and return to campus for their senior year to graduate on schedule with their class.

## International Programs

An international perspective, sensitivity to other cultures, and the ability to read and speak a second language are increasingly important for today's engineers. In keeping with the university goals of internationalizing the curriculum, the College of Engineering encourages students to study or work abroad during their undergraduate years. For information on these and other opportunities to add an international dimension to your undergraduate education, visit Engineering Advising, 167 Olin Hall. For information on an international co-op work experience, visit the Engineering Cooperative Education and Career Services office, 201 Carpenter Hall.

Students who plan to study abroad apply through Cornell Abroad; please see the Cornell Abroad program description in the introductory section of *Courses of Study*.

### Cooperative Program with the Johnson Graduate School of Management

Undergraduates may be interested in a cooperative program at Cornell that leads to both master of engineering and master of business administration (M.B.A.) degrees. See the section "Master of Engineering Degrees" for details.

### Lester Knight Scholarship Program

The Lester Knight Scholarship Program is designed to assist and encourage Cornell Engineering students and alumni interested in combining their engineering education with a business degree. See the section "Master of Engineering Degrees" for details.

## ACADEMIC PROCEDURES AND POLICIES

### Advanced Placement Credit

The College of Engineering awards a significant amount of advanced placement (AP) credit to entering freshmen who demonstrate proficiency in the subject areas of introductory courses. Students can earn AP credit by receiving qualifying scores on any of the following:

1. Advanced placement examinations given and scored by the College Entrance Examination Board (CEEB);
2. General Certificate of Education (GCE) Advanced ("A") Level Examinations;
3. International Baccalaureate (IB) Higher Level Examinations; or
4. Cornell's departmental placement examinations, given during orientation week before the beginning of fall-term classes.

Advanced placement credit is intended to permit students to develop more challenging and stimulating programs of study. Students who receive AP credit for an introductory course may use it in three different ways. They may:

1. enroll in a more advanced course in the same subject right away.
2. substitute an elective course from a different area.
3. enroll in fewer courses, using the AP credit to fulfill basic requirements.

### Acceptable Subjects and Scores for CEEB or Cornell Departmental AP Exams

The most common subjects for which AP credit is awarded in the College of Engineering, and the scores needed on qualifying tests, are listed below. AP credit is awarded only for courses that meet engineering curriculum requirements.

**Mathematics:** MATH 191 (or 190), 192 are required.

*First-term math (MATH 191).* AP credit may be earned by:

- a score of "4" or "5" on the CEEB BC exam, or
- a passing score on the Cornell departmental exam for first-term math.

*First-year math (through MATH 192).* AP credit may be earned by:

- a passing score on the Cornell departmental exam for first-year math.

**Physics:** PHYS 112 and 213 are required.

*PHYS 112.* AP credit may be earned by:

- a score of "4" or "5" on the mechanics portion of the CEEB C exam, or
- a score of "5" on the CEEB B exam *only* if the student has at least one semester of AP or transfer credit in first-term math at the time of matriculation, or
- a passing score on the Cornell departmental exam for PHYS 112.

**Note:** Students who have received credit for PHYS 112 may not enroll in PHYS 213 unless concurrently enrolled in MATH 293.

*PHYS 213.* Students receiving a "5" on the Electricity and Magnetism portion of the AP C exam may choose to accept AP credit for PHYS 213 or to enroll in PHYS 213 with no AP credit.

*PHYS 116, 217, and 218* (honors sequence). This sequence is designed for students with strong experience in physics and calculus, e.g., "5"s on one or both Physics C AP tests and the equivalent of at least one semester of university calculus. Students interested in PHYS 217 or 218 are strongly advised to start with PHYS 116. Even for a student with "5"s on both Physics C AP tests, 116 will not be boring. Students cannot simultaneously receive credit for PHYS 116 and AP credit for PHYS 112, or credit for PHYS 217 and AP credit for PHYS 213. For advice or more information, contact the departmental representative at 255–6016.

**Chemistry:** CHEM 207 or CHEM 211 is required.

*CHEM 207 or CHEM 211.* AP credits may be earned by:

- a score of "5" on the CEEB AP exam, or
- a passing score on the Cornell departmental exam for chemistry.

**Note:** Students who obtain AP credit for CHEM 207 and who are considering a major in Chemical Engineering or Materials Science and Engineering should consider enrolling in CHEM 215. Those who are offered AP credit for CHEM 207 and then elect to take CHEM 215 will also receive academic credit for CHEM 207. You may want to discuss this option with your faculty adviser.

**Computing:** COM S 100 is required. AP credit may be earned by:

- a score of "5" on the CEEB A or a score of "4" or "5" on the AB exam, or
- a passing score on the Cornell departmental exam for COM S 100.

**Biology:** Biology is not required, although it is a popular elective, especially for students who intend to pursue health-related careers. AP credit may be earned as follows:

- 8 credits will be offered to students who receive a "5" on the CEEB AP exam;
- 6 credits will be offered to students who receive a "4" on the CEEB AP.

Those who want to study more biology should contact the Office of Undergraduate Biology, 200 Stimson Hall, to discuss proper placement.

**First-year writing seminar:** Two first-year writing seminars are required.

- AP credit for one first-year writing seminar may be earned by a score of "5" on either of the CEEB AP English exams.

Students who earn a score of "4" on the AP English Literature and Composition exam or the AP English Language and Composition exam will be offered 3 credits, which may be applied toward the Literature and Arts (LA) category of the Liberal Studies distribution requirement.

**Liberal studies distribution:** Six courses beyond two first-year writing seminars are required. Students may earn AP credit toward the liberal studies distribution by taking College Entrance Examination Board (CEEB) AP tests. AP credit earned in the liberal studies distribution cannot be used to fulfill the "upper-level" liberal studies requirements.

**Modern languages:** Students may earn AP credit for competence in a foreign language by taking the College Entrance Examination Board (CEEB) AP test or by taking the Cornell Advanced Standing Examination (CASE). Those who score 4 or 5 on the CEEB AP test are entitled to 3 credits. To qualify for the CASE exam, the student must score at least 650 on a college placement test (taken either in high school or at Cornell during Orientation Week). A score of "2" on the CASE entitles the student to 3 credits; a score of "3," 6 credits, which are equivalent to two courses. Modern language AP credits may be used to satisfy the foreign language category of the liberal studies distribution or may meet an approved elective requirement, contingent on discussions with the faculty adviser.

### Advanced Placement and Credit for International Credentials

Students who have successfully completed either a General Certificate of Education (GCE) Advanced ("A") Level Examination or an International Baccalaureate (IB) Higher Level Examination may be eligible for advanced placement credit in the College of Engineering as follows:

**General Certificate of Education Advanced Level Examination (GCE "A")**

Hong Kong Advanced Level examinations and the joint examination for the Higher School Certificate and Advanced Level Certificate of Education in Malaysia and Singapore—principal passes only—are considered equivalent in standard to GCE "A" Levels.

| *Subject* | *Marks* | *Credit* |
|---|---|---|
| Biology | A or B | 8 credits |
| Chemistry | A | 8 credits (CHEM 207 and 208) |
| | B | 4 credits (CHEM 207) |
| Mathematics | A, B, or C | 4 credits (MATH 191/190) |
| Physics | A or B | 4 credits for PHYS 112; 4 additional credits for PHYS 213 are granted to a combination of grades of A or B and a minimum of 4 Advanced Placement (or advanced standing) credits in mathematics. |

**International Baccalaureate (IB) Higher Level Examination**

| *Subject* | *Marks* | *Credit* |
|---|---|---|
| Biology | 7 | 8 credits |
| | 6 | 6 credits |
| Chemistry | 6 or 7 | 4 credits (CHEM 207 or CHEM 211) |
| Computer Science | 6 or 7 | 4 credits (COM S 100) |
| Mathematics | 6 or 7 | 4 credits (MATH 191/190) |
| Physics | 6 or 7 | 4 credits (PHYS 112) |

**Note:** Advanced placement credit based on GCE or IB results may also be awarded for courses that satisfy the liberal studies requirement in the College of Engineering. In such cases, the College of Engineering follows the AP guidelines found earlier in this publication under "General Information."

## General Policies for Advanced Placement

The general policies in the College of Engineering governing awards of AP credit are as follows:

1. AP credit will not be offered in any subject area without a documented examination.
2. All AP examinations are normally taken and scored before fall-term classes begin. Students who take CEEB AP tests in high school should have an official report of their scores sent directly to Cornell as soon as possible. Students who have completed either GCE "A" Level or IB Higher Level Examinations must present the original or a certified copy of their examination certificate to Engineering Advising, 167 Olin Hall. Those who wish to take departmental examinations should do so during Orientation Week; permission to take these tests after the start of fall-term classes must be requested in a written petition to the college's Committee on Academic Standards, Petitions, and Credit (ASPAC).

A more detailed description of the college's policies concerning advanced placement credit and its use in developing undergraduate programs may be found in the pamphlet *Advanced Placement and Transfer Credit for First-Year Engineering Students,* which may be obtained from Engineering Advising, 167 Olin Hall.

## Transfer Credit for First-Year and Continuing Students

Undergraduate students who have completed courses at recognized and accredited colleges may, under certain conditions, have credits for such courses transferred to Cornell. Such courses must represent academic work in excess of that required for the secondary school diploma and must be documented as such in writing by the secondary institution. Courses deemed acceptable for transfer credit must be equivalent in scope and rigor to courses at Cornell. Transfer credit will not be awarded for courses taken during a semester in which the student is enrolled at Cornell.

- To apply for transfer credit, submit a Transfer Credit Form (one form for each request), accompanied by a course description. (Forms are available from Engineering Advising or the Registrar's Office and should be submitted before enrollment.) An official transcript from the offering institution (bearing the institutional seal and registrar's signature) must be sent to the Engineering Registrar's office before official transfer credit will be awarded.
- Applications for transfer credit to satisfy requirements in math, science, engineering courses, or first-year writing seminars require approval from the department offering an equivalent course at Cornell. The department may require course materials, textbooks used, etc., in addition to the course description before approving the course.
- Departmental approval is not required for transfer credit that satisfies liberal studies distribution requirements. The course will be reviewed for approval by a representative of the Committee on Academic Standards, Petitions, and Credit (ASPAC) in Engineering Advising.
- Cornell does not award credit for courses in which a student has earned a grade less than C; schools and departments may stipulate a higher minimum grade.
- College courses completed under the auspices of cooperative college and high school programs will be considered for advanced placement credit only if students demonstrate academic proficiency by taking the appropriate AP or Cornell departmental placement examination, as described in the "Advanced Credit" section.
- Following matriculation, students may apply up to 18 credits of transfer and/or Cornell extramural credit toward B.S. degree requirements.
- At most 72 total transfer credits (taken both before and after matriculation) may be used to meet graduation requirements.
- Summer session courses taken at Cornell are not considered transfer credit.

A more detailed description of the college's regulations governing transfer credit may be found in the pamphlet *Advanced Placement and Transfer Credit for First-Year Engineering Students* as well as the *Engineering Undergraduate Handbook*, both available from Engineering Advising, 167 Olin Hall.

## Transfer Credit for Transfer Students

Transfer students may transfer up to 36 credits for each year spent in full-time study at another institution, provided that the courses are acceptable for meeting graduation requirements. Transfer credit is determined by the majors.

## Academic Standing

Full-time students are expected to remain in good academic standing. The criteria for good standing change somewhat as a student progresses through the four years of the engineering curriculum. At all times, the student must be making adequate progress toward a degree, but what this actually means depends on the major.

Requirements for freshman engineering students to be in good standing at the end of the first semester are as follows. Failure to meet these standards will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC), and the actions of warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may be taken.

1. At least 12 credits passed, including at least two courses from math, science, and/or engineering (phys. ed. courses and courses below the 100 level do not count)
2. At least C- in the math course
3. Semester GPA $\geq 2.0$
4. No F, U, or INC grades

Requirements for unaffiliated second-semester freshmen and sophomores to be in good standing are as follows. Failure to meet these requirements will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC); a warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may result.

1. At least 14 credits passed in courses that meet B.S. degree requirements, normally at least two math, science, or engineering courses (phys. ed. courses and courses below the 100 level do not count)
2. At least C- in a math course, if one was taken
3. Semester GPA $\geq 2.0$
4. No F, U, or INC grades

## Academic Progress

The total number of credits required for graduation range from 123 to 133, depending on the major. Therefore, an average semester credit load ranges from 15 to 17 credits.

Because math is pivotal to the study and practice of engineering, students must earn at least C- in their four required math courses. If at least C- is not attained, the course must be repeated immediately. Failure to achieve at least C- the second time will generally result in withdrawal from the College of Engineering. Physics and advanced math courses often have math prerequisites, and having to repeat the prerequisite course may delay progress in the physics and math curricula. Students are expected to continue the core engineering math courses each semester until completed.

## Dean's List

Dean's List citations are presented each semester to engineering students who have exemplary academic records. The dean of the college determines the criteria for this honor. For 2004–2005, the requirement is a semester GPA ≥ 3.4 (without rounding); no failing, unsatisfactory, missing, or incomplete grades (even in physical education); and at least 12 letter-grade credits (not S-U). Students may earn Dean's List status retroactively if they meet these criteria after making up incomplete grades. Students who earn Dean's List status receive certificates from the Engineering Registrar's Office, and the honor is noted on the transcript.

## Graduating with Distinction and Honors

### Graduating with Distinction

Meritorious students graduating with a B.S. degree from the College of Engineering may also be designated *cum laude, magna cum laude,* or *summa cum laude.*

- Cum laude will be awarded to engineering students with a GPA ≥ 3.5. Cum laude will also be awarded to engineering students who received a semester GPA ≥ 3.5 in each of the last four semesters at Cornell; in each of these semesters, at least 12 letter-graded credits must be taken with no failing, unsatisfactory, missing, or incomplete grades. If the student is an engineering co-op student, then the engineering co-op summer term will count as one of the last four. Students who were approved for pro-rated tuition in their final semester will be awarded cum laude if they received a semester GPA ≥ 3.5 in their last semester and meet the conditions above in the prior four semesters.
- Magna cum laude will be awarded to engineering students with a GPA ≥ 3.75 (based on all credits taken at Cornell).
- Summa cum laude will be awarded to engineering students with a GPA ≥ 4.0 (based on all credits taken at Cornell).

**Note:** All GPA calculations are minimums and are not rounded.

### Major Honors Program

To be eligible for major honors, a student must enter a major with and maintain a cumulative GPA ≥ 3.5. If the major has an approved honors program and both the GPA and program requirements are fulfilled, the faculty of the major may recommend that a student graduate with the additional diploma and transcript notation of "With Honors." For more information, see the section "Engineering majors."

## S-U Grades

Many courses may be taken either for a letter grade or for an S-U (satisfactory or unsatisfactory) grade designation. Under the S-U option, students earning the letter grade equivalent of at least C- in a course will receive a grade of S; those earning less than C- receive U. (A course in which a U grade is received does not count toward graduation requirements.)

Engineering students may choose to receive an S-U grade option under the following conditions:

- The course in question must be offered with an S-U option.
- The student must previously have completed at least one full semester of study at Cornell.
- The proposed S-U course must count as either a liberal studies distribution or an adviser-approved elective in the engineering curriculum.
- Students may enroll S-U in only one course each semester in which the choice between letter grade and S-U is an option. (Additional courses offered "S-U only" may be taken in the same semester as the "elected S-U" course.)

The choice of grading option for any course is made initially during the pre-enrollment period. Grading options may be changed, however, by submitting a properly completed Add/Drop Form to the Engineering Registrar by the end of the third week of classes. After this deadline, the grading option may not be changed, nor will a student be permitted to add a course in which he or she was previously enrolled (in the current semester) under a different grade option.

## Residence Requirements

Candidates for an undergraduate degree in engineering must spend at least four semesters or an equivalent period of instruction as full-time students at Cornell. They must also spend at least three semesters of this time affiliated with an engineering major.

Students on a voluntary leave of absence are permitted to register for courses extramurally only with the approval of their major (or the college, for unaffiliated students). No more than 18 credits earned through extramural study or acquired as transfer credit (or a combination thereof) after matriculation may be used to satisfy the requirements for the B.S. degree in engineering. Students may not complete their last semester extramurally.

Degree candidates may spend periods of time studying away from the Cornell campus with appropriate authorization. Information on programs sponsored by other universities and on procedures for direct enrollment in foreign universities is available at the Cornell Abroad Office, 474 Uris Hall. Programs should be planned in consultation with the staff of Engineering Advising, who can provide information on credit-evaluation policies and assist in the petitioning process.

## Transferring within Cornell

It is not uncommon for students to change their academic or career goals after matriculation in one college and decide that their needs would be better met in another college at Cornell. While transfer between colleges is not guaranteed, efforts are made to assist students in this situation.

The office responsible for assisting students with the transfer process is the Internal Transfer Division Office. Students who wish to transfer out of the College of Engineering to another college at Cornell should consult initially with Engineering Advising.

Students who wish to transfer into the College of Engineering can apply at Engineering Advising—application forms are available in 167 Olin Hall. It is preferred that students apply in the semester in which they are completing affiliation criteria for the desired major. Students who would enter the college as a second-semester sophomore or later must be accepted by a major as part of the admission process. Students who would enter as a second-semester freshman or first-semester sophomore may be accepted into the college without the requirement of major affiliation but must be sponsored by a major.

Students who wish to transfer into engineering should take courses in math, chemistry, computer science, physics, and engineering that conform to the requirements of the Common Curriculum. Students should discuss their eligibility with an adviser in Engineering Advising, 167 Olin Hall.

## Leave of Absence

A leave of absence may be voluntary, medical, or required. A description of each follows:

**Voluntary leave:** Students sometimes find it necessary to suspend their studies. To do this, they must petition for a leave of absence for a specified period of time and receive written approval.

Affiliated students request leave through their majors. Unaffiliated students request leave through Engineering Advising; the first step is an interview to establish conditions for the leave and subsequent return. Those who take a leave before affiliating with a major and while not in good standing may be given a "conditional leave." This requires them to meet specific conditions, established at the time the leave is granted, before they will be reinstated.

Leaves of absence generally are not granted for more than two years. A leave of absence granted during a semester goes into effect on the day it is requested and lasts for a *minimum of six months.* If a leave is requested after the twelfth week of a semester, the courses in which the student was registered at the time of the request are treated as having been dropped (i.e., a "W" will appear on the transcript for each course). Students who owe money to the university are ineligible for leaves of absence. If courses taken during a leave are to satisfy Cornell degree requirements, they must be approved *in advance* through a formal transfer petition. (See previous section, "Transfer Credit," for details.)

Students who intend to take a leave of absence should check with the Office of Financial Aid and Student Employment to discuss financial implications; this is especially true for those who have taken out educational loans. Medical insurance eligibility may also be affected.

To return after a leave of absence, the conditions established when the leave was granted must be satisfied, and the college must be notified in writing at least six weeks before the beginning of the semester in which the student plans to return.

**Medical leave:** Medical leaves are granted by the college only upon recommendation by a physician or therapist from Gannett Health Center. Such leaves are granted for at least six months and up to two years with the understanding that the student may return at the beginning of any term after the medical condition in question has been corrected. Students must satisfy the Gannett Health Center that the condition has been corrected before they may return. The student's academic standing will also be subject to review both at the time the leave is granted and upon the student's return.

**Required leave:** A required leave of absence is imposed in cases where the academic progress of a student is so poor that continuing into the next semester does not appear prudent. An example where a leave of absence would be required might be failure in key engineering courses in a semester. Unless the student is ahead in the curriculum, returning later to repeat the semester makes better academic sense than continuing without the necessary background. In many cases, the leave is dictated by courses that are offered only in the fall or spring semester. Leaves are given when the probability of success is increased substantially by deferring the student's return by one semester (or, in unusual circumstances, one year).

### Rejoining the College

Students wishing to rejoin the college who have not yet affiliated with a major should request permission to rejoin in a letter to Engineering Advising; affiliated students should contact their major office. This must be done at least six weeks before the beginning of the semester in which the student wishes to return. The letter should describe the student's activities while away from Cornell, detail any academic work completed during this time, and specify the courses the student intends to take upon return.

### Withdrawal from the College

A withdrawal from the College of Engineering may be voluntary or required. Following is a description of each:

**Voluntary withdrawal:** Students who voluntarily withdraw from the college sever all connection with the college. Unaffiliated students who wish to withdraw should do so through Engineering Advising. Affiliated students should contact their major office. If a withdrawal is requested during the semester, courses in which the student is enrolled must be dropped in accordance with applicable regulations.

A student who fails to register in the first three weeks of the semester, without benefit of a leave of absence or permission for study in absentia, will be deemed to have withdrawn.

Students who withdraw from the College of Engineering are eligible to apply for admission to one of the other six colleges at Cornell. The intrauniversity transfer process should be followed.

A student who has withdrawn and subsequently wishes to return must make a formal application for readmission. This is rarely granted. It is subject to a review of the student's academic background and depends on available space in the college and in the student's major.

**Required withdrawal:** Students are required to withdraw from the college only when their overall record indicates that they are either incapable of completing the program or not sufficiently motivated to do so. This action withdraws them only from the College of Engineering and does not, in and of itself, adversely affect their ability to transfer and complete a degree in one of the other colleges in the university.

## ENGINEERING MAJORS

This section describes the majors in the College of Engineering: the programs in which an undergraduate can study to obtain a B.S. degree.

A basic requirement of any major is a GPA $\geq$ 2.0. Most majors have a higher GPA requirement and may have other requirements.

### Honors Program within Majors

Many of the Engineering majors supplement the major with an honors program.

#### Eligibility

The B.S. degree with honors is granted to engineering students who, *in addition* to having completed the requirements for a B.S. degree in a major, satisfactorily complete the honors program in the major and are recommended for the degree by the honors committee of that major. An honors program student must enter with and maintain a cumulative GPA $\geq$ 3.5. If the GPA drops below 3.5, the student is dropped from the honors program.

Courses taken to satisfy the honors requirement may not be used to satisfy B.S. degree requirements. At least 9 extra credit hours are required, and a student must be in the program for at least two semesters before graduation.

No research, independent study, or teaching for which the student is paid may be counted toward the honors program.

#### Procedures

An applicant to the honors program in a major must have an honors adviser, a faculty member from that major who will supervise the honors program and direct the research or project. The honors adviser need not be the student's adviser in the major.

The application for the honors program should be a letter from the student that describes the proposed honors program in detail and includes the explicit approval of the honors adviser.

Students must complete a written application no later than the beginning of the first semester of their senior year, but they are encouraged to make arrangements with the honors adviser during the second semester of their junior year. Each major may place further constraints on timing.

#### Major-Specific Information

Each major defines the content of the honors program and may also place other requirements on the program, in terms of timing, content, and procedures. Information is given within the description of the individual majors.

## BIOLOGICAL ENGINEERING

Offered by the Department of Biological and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255–2173, www.bee.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Biological and Environmental Engineering (BEE) addresses three great challenges facing humanity today: ensuring an adequate and safe food supply in an era of expanding world population; protecting and remediating the world's natural resources, including water, soil, air, biodiversity, and energy; and developing engineering systems that monitor, replace, or intervene in the mechanisms of living organisms. The Biological Engineering major has a unique focus on biological systems, including the environment, which is realized through a combination of fundamental engineering sciences, biology, engineering applications and design courses, and liberal studies.

An option in Environmental Engineering is discussed further below.

Students interested in the BE major should have a strong aptitude for the sciences and math and an interest in the complex social issues that surround technology.

Students take courses in math, statistics, computing, physics, chemistry, basic and advanced biology, fundamental engineering sciences (mechanics, thermodynamics, fluid mechanics, and transport processes), and engineering applications. Students select upper-level engineering courses in subjects that include bioprocessing, soil and water management, biotechnology applications, bioinstrumentation, engineering aspects of animal physiology, environmental systems analysis, and waste treatment and disposal. Students may further strengthen their programs by completing a minor or a second engineering major. Students planning for medical school also take additional lab-based courses in biology, biochemistry, and organic chemistry. Throughout the curriculum, emphasis is placed on communications and teamwork skills, and all students complete a capstone design project.

Career opportunities cover the spectrum of self-employment, private industry, public agencies, educational institutions, and graduate and professional programs in engineering and science, as well as professional fields like medicine, business, and law. In recent years, graduates have developed careers in environmental consulting, biotechnology, the pharmaceutical industry, biomedical engineering, management consulting, and international development.

The living world is all around us, and within us. The biological revolution continues, and it has given rise to a growing demand for engineers and technical people who have studied biology and the environment, who have strong math and science skills, who can communicate effectively, and who are sensitive to the needs of people and interested in the challenges facing society. This major is designed to educate the next generation of engineers to meet these challenges.

The major program requirements for students affiliating with the program in 2004–2005 are outlined below.

| *Basic Subjects* | *Credits* |
|---|---|
| MATH 191 (or 190), 192, 293, 294 | |
| Calculus for Engineers and Engineering Mathematics | 16 |
| PHYS 112, 213 | 8 |
| General Chemistry (207 or 211 or 215)* | 4 |
| Organic Chemistry (257 or 357)* | 3 |
| BEE 151, Introduction to Computing or COM S 100 | 4 |
| Biological Sciences* | 15 |
| Introductory (BIO G 101–104 recommended) | 6–8 |
| Biochemistry or Microbiology | 4–5 |
| BIO XXX Biological science course(s) ≥ 200 | 3–5 |
| *Major-required courses* | |
| BEE 200, The BEE Experience or ENGRG 150 | 1 |
| ENGRD 202, Mechanics of Solids | 4 |
| BEE 251 or BEE 260, ENGR Applications | 3 |
| BEE 350, Biological and Environmental Transport Processes | 3 |
| BEE 222 or M&AE 221, Thermodynamics | 3 |
| Engineering Statistics and Probability (ENGRD 270 or CEE 304) | 3 |
| Fluid Mechanics (CEE 331 or M&AE 323 or CHEME 323) | 3–4 |
| Upper-level BEE courses (3 courses numbered 450–489; at least one of these must be an approved capstone design course) | 9 |
| Major-approved electives and electives outside the major (200 level or above; at least one must be an approved laboratory experience course; at least one must be a BEE capstone course) | 18–19 |
| Liberal studies (two first-year writing seminars and six liberal-studies electives) | 24 |
| Adviser-approved electives | 6 |
| Total (minimum) | 126 |

*Basic accredited curriculum. Specializations (options or preprofessional study) may be accommodated by selecting additional courses in the indicated area(s).

## Biological Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

The 9 credits beyond the B.S. degree requirements shall be drawn from the following, with at least 4 credits in the first category:

1. A significant research experience or honors project under the supervision of a BEE faculty member using BEE 499, Undergraduate Research. A written senior honors thesis must be submitted as part of this component.
2. A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the department under BEE 498, Undergraduate Teaching.
3. Advanced or graduate courses. These additional courses must be technical in nature, i.e., in engineering, math, biology, chemistry, and physics at the 400+ and graduate level.

## Option in Environmental Engineering

The Environmental Engineering Option provides BE majors the opportunity to follow a structured environmental engineering concentration. Students complete a prescribed program of courses within the framework of the BE curriculum.

Chemistry/microbiology: Students must take at least two semesters of chemistry (CHEM 211/257 or CHEM 207/208). They must also satisfy the BE organic chemistry requirement either by taking organic chemistry as one of the two required chemistry courses (i.e., CHEM 257) or by taking CEE 451. The microbiology requirement of the Environmental Engineering option can also be met by taking CEE 451.

Chemistry: CHEM 211/257 or CHEM 207/208

Organic Chemistry: CHEM 257 or CEE 451

Microbiology: CEE 451 or BIOMI 290

Fluid Mechanics: CEE 331

Probability and Statistics: CEE 304

Environmental Quality Engineering: CEE 351

Environmental Engineering Lab: CEE 453

Environmental Engineering: BEE 473 or 475: Watershed Engineering or Environmental Systems Analysis

# CHEMICAL ENGINEERING

Offered by the School of Chemical and Biomolecular Engineering

Contact: 120 Olin Hall, 255-8656, www.cheme.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

The undergraduate major in Chemical Engineering comprises a coordinated sequence of courses beginning in the sophomore year and extending through the fourth year. Students who plan to enter the major take CHEM 208 during the freshman year. The program for the last three years is as follows:

| *Semester 3* | *Credits* |
|---|---|
| MATH 293, Engineering Mathematics | 4 |
| PHYS 213, Electricity and Magnetism | 4 |
| CHEM 389, Physical Chemistry I (engineering distribution) | 4 |
| ENGRD 219, Mass and Energy Balances (engineering distribution) | 3 |
| Humanities or social sciences | 3 |
| *Semester 4* | |
| MATH 294, Engineering Mathematics | 4 |
| CHEME 323, Fluid Mechanics | 3 |
| CHEM 290–391, Physical Chemistry (field) | 6 |
| Biology elective | 3 |
| Humanities or social sciences | 3 |
| *Semester 5* | |
| CHEM 357, Organic Chemistry for the Life Sciences | 3 |
| CHEM 251, Organic Chemistry Laboratory | 2 |
| CHEME 313, Chemical Engineering Thermodynamics | 3 |
| CHEME 324, Heat and Mass Transfer | 3 |
| Humanities or social sciences | 3 |
| *Semester 6* | |
| Advanced science elective | 3 |
| CHEME 301, Nonresident Lectures | 1 |
| CHEME 332, Analysis of Separation Processes | 3 |
| CHEME 372, Introduction to Process Dynamics and Control | 2 |
| CHEME 390, Reaction Kinetics and Reactor Design | 3 |
| Humanities or social sciences | 3 |
| *Semester 7* | |
| CHEME 432, Chemical Engineering Laboratory | 4 |
| Electives* | 9 |
| Humanities or Social Sciences | 3 |
| *Semester 8* | |
| CHEME 462, Chemical Process Design | 4 |
| Humanities or social sciences | 3 |
| Electives* | 3 |
| Approved elective | 3 |

*The electives in semesters 7 and 8 comprise 6 credits of major-approved electives and 6 credits of advanced CHEME electives. Advanced CHEME electives include any CHEME course at the 400+ level except CHEME 490, 491, 492, 520, 572, and 601.

Advanced science electives include BIOMI 290, General Microbiology Lectures; BIOBM 330, 331, 332, and 333, Principles of Biochemistry; BMEP (CHEME) 401, Molecular Principles of Biomedical Engineering; BMEP (CHEME) 402, Cellular Principles of Biomedical Engineering; CEE 451, Microbiology for Environmental Engineering; CEE 654, Aquatic Chemistry; CHEME 470, Process Control Strategies; CHEME 480, Chemical Processing of Electronic Materials; CHEME 481, Biomedical Engineering; CHEME 484, Microchemical and Microfluidic Systems; CHEME 640, Polymeric Materials; CHEME 543, Bioprocess Engineering; CHEME 661, Air Pollution Control; FOOD 417, Food Chemistry I; M&AE 423, Intermediate Fluid Dynamics; MS&E 206, Atomic and Molecular Structure of Matter; MS&E 305, Electronic Structure of Matter; MS&E 306, Electrical, Optical, and Magnetic Properties of Materials; MS&E 521, Properties of Solid Polymers; MS&E 531, Introduction to Ceramics; MS&E 541, Microprocessing of Materials; T&AM 310, Advanced Engineering Analysis I; any A&EP course numbered 333 or above; any CHEM course numbered 301 or above; any PHYS course numbered 300 or above.

# CIVIL ENGINEERING

Offered by the School of Civil and Environmental Engineering

Contact: 221 Hollister Hall, 255–3412, www.cee.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

While it is not necessary to do so, students may concentrate in civil infrastructure, fluid mechanics and hydrology, geotechnical engineering, structural engineering, transportation, or water resource systems.

## Admission Requirements

Students planning to affiliate with this major must complete ENGRD 202, Mechanics of Solids, by the end of the first semester of the sophomore year with at least C–.

## Engineering Distribution Courses

Majors are required to take ENGRD 202, Mechanics of Solids, as an engineering distribution course. For the second engineering distribution course, one of the following is recommended:

ENGRD 261, Introduction to Mechanical Properties of Materials, for students interested in structural engineering or civil engineering materials; strongly recommended for those concentrating in civil infrastructure.

ENGRD 201, Introduction to the Physics and Chemistry of the Earth, for students interested in geotechnical engineering.

ENGRD 221, Thermodynamics, for students interested in fluid mechanics and hydraulics/hydrology.

ENGRD 211, Computers and Programming, for students interested in transportation.

## Major Program

Students may substitute CHEM 208 for PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum.

| *Core Courses* | *Credits* |
|---|---|
| ENGRD 203, Dynamics, or CEE 478, Structural Dynamics | 3 |
| ENGRD 241, Engineering Computation* | 3 |
| CEE 304, Uncertainty Analysis in Engineering† | 4 |
| CEE 323, Engineering Economics and Management | 3 |
| CEE 331, Fluid Mechanics | 4 |
| CEE 341, Introduction to Geotechnical Engineering and Analysis | 4 |
| CEE 351, Environmental Quality Engineering** | 3 |
| CEE 361, Introduction to Transportation Engineering** | 3 |
| CEE 371, Modeling of Structural Systems | 4 |

Additional requirements include a set of two major-approved electives and three design electives from a list of approved courses that is available in the school office. In addition, students must complete one technical communications course from among the courses designated ENGRC or approved communications courses. If the technical communications course is taken as an expressive art, then an additional approved elective must be taken from a department or school other than Civil and Environmental Engineering.

*ENGRD 241 can be used to satisfy a major requirement. If a student elects to use this course as a second distribution course, the student must take an additional major-approved elective to fulfill the core course requirements.

†ENGRD 270 may be accepted (by petition) as a substitute for CEE 304 in the major, but only if ENGRD 270 is taken before affiliation, or in some special cases where co-op or study abroad programs necessitate such a substitution.

**Students may substitute any major-approved elective for either CEE 351 or CEE 361, if they complete either CEE 376 or CEE 472 and also complete CEE 473. However, this substitute course then counts as a core course only and not as one of the required five CEE design courses and major-approved electives.

## Civil Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

The 9 credits beyond the B.S. degree requirements shall be drawn from the following components:

1. A significant research experience or honors project under the direct supervision of a CEE faculty member using CEE 400: Senior Honors Thesis (1–6 credits per semester). A significant written report or senior honors thesis must be submitted as part of this component. Letter grade only.
2. A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the College of Engineering, i.e., ENGRG 470, Peer Teaching in Engineering, or CEE 401, Undergraduate Teaching in CEE (1–3 credits per semester).
3. Advanced or graduate courses at the 500 level or above. The minimum number of credits in any component included in a program should be 2.

### Procedures

Application to the program shall be a registration form for CEE 400 and a letter from the student describing the specific proposed honors program and including the explicit approval of the major adviser and the honors adviser. The program must be approved by the CEE Curriculum Committee, although the committee may delegate approval authority to the associate director for all but unusual proposals.

# COMPUTER SCIENCE

Offered by the Department of Computer Science

Contact: 303 Upson Hall, 255–0982, www.cs.cornell.edu

The Department of Computer Science is affiliated with both the College of Arts and Sciences and the College of Engineering. Students in either college may major in computer science.

Computer Science majors take courses in algorithms, data structures, logic, programming languages, scientific computing, systems, and theory. Electives in artificial intelligence, computer graphics, computer vision, databases, multimedia, and networks are also possible. Requirements include:

- four semesters of calculus (MATH 191–192–293–294)
- two semesters of introductory computer programming (COM S 100 and ENGRD 211)
- a 1-credit project (COM S 212)
- a seven-course computer science core (COM S 280, 312, 314; one of 321, 322, 421, or 428; 381, 414, and 482)
- two 400+ level computer science electives, totaling at least 6 credits
- a computer science project course (COM S 413, 415, 419, 427, 433, 468, 473, 501, 514, or 664)
- a math elective course (e.g., ENGRD 270, MATH 300+, T&AM 310)
- two 300+ level courses (major-approved electives) that are technical in nature and total at least 6 credits
- three courses in a topic area other than computer science, all numbered 300 level or greater

All the major electives described above must be courses of at least 3 credits, with the exception of the COM S project course, which is at least 2 credits.

The program is broad and rigorous, but it is structured in a way that supports in-depth study of outside areas. Intelligent course selection can set the stage for graduate study or employment in any technical area or any professional area such as business, law, or medicine. With the adviser, the computer science major is expected to put together a coherent program of study that supports career objectives and is true to the aims of a liberal education.

## Computer Science Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" with a set of coherent courses and research activities that satisfy the following requirements.

1. at least one COM S course (at least 3 credit hours) at or above the 500 level with at least A- (no seminars or 2-credit project courses)
2. at least two 3-credit semesters of COM S 490 (independent research), with at least A- each semester

Honors determinations are made during the senior year. Students wanting to be considered for the honors program should notify the undergraduate office in the Department of Computer Science at ugrad@cs.cornell.edu. The subject line for this message should read "HONORS TRACK." Address related questions to the same e-mail address; call or stop by 303 Upson Hall, 255–0982; or visit www.cs.cornell.edu/ugrad for more information on eligibility.

# ELECTRICAL AND COMPUTER ENGINEERING

Offered by the School of Electrical and Computer Engineering

Contact: 223 Phillips Hall, 255–4309, www.ece.cornell.edu

This major is accredited under the title "Electrical Engineering" by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

The Electrical and Computer Engineering major, leading to a B.S. degree, provides a foundation that reflects the broad scope of this engineering discipline.

Concentrations include computer architecture and organization, digital systems and computer vision; power systems, control, optimization, numerical and state-space methods; communications, computer networks, information theory and coding, signal processing; electronic circuits, VLSI, solid state physics and devices, MEMs, nanotechnology, lasers and optoelectronics; electromagnetics, radiophysics, space sciences, plasmas.

Students planning to affiliate with ECE must take ENGRD 230 as an engineering distribution course. Prospective majors are encouraged, but not required, to take ENGRD 211 as the other engineering distribution course. The major normally begins in the spring of the sophomore year. Of the courses listed below, only ENGRD/ECE 210, ECE 220, ENGRD 230, CS/ECE 314, and ECE 315 are taught in both the fall and spring semesters.

| *Course* | *Credits* |
|---|---|
| **Major-required courses** | |
| ECE/ENGRD 210, Introduction to Circuits for Electrical and Computer Engineers | 4 |
| ENGRD 230, Introduction to Digital Logic Design | 4 |
| ECE 220, Signals and Information | 4 |
| ECE 303, Electromagnetic Fields and Waves | 4 |
| ECE/COM S 314, Computer Organization | 4 |
| ECE 315, Introduction to Microelectronics | 4 |
| ECE 320, Systems and Networks | 4 |
| **Major-Approved Electives** *(32-credit minimum in the following categories)* | |
| Advanced ECE electives† | (6 lecture courses) |
| Outside ECE electives‡ | 9 minimum credits |
| Total minimum major credits | 53 |

ECE 310 can be taken in place of ENGRD 270 or T&AM 310 to satisfy the college application of probability and statistics requirement.

†These electives must include two 400-level electrical and computer engineering culminating design experience (CDE) courses and at least two additional courses at the 400 level or above. The remaining electives may not include independent project courses, such as ECE 391, 392, 491, or 492, and must be at the 300 level or above in Electrical and Computer Engineering.

Courses that meet the CDE requirement are described in the *Engineering Undergraduate Handbook*. (The list is dynamic and changes frequently. Always refer to the latest information in the *Electrical and Computer Engineering Web Handbook*.) All courses must have a college-level prerequisite.

‡Must include one course at the 300 level or above (see *Electrical and Computer Engineering Web Handbook* for details).

The technical-writing requirement is discussed in the "College of Engineering" section of this book.

Undergraduate concentration is achieved through the various electrical and computer engineering elective courses, as well as other courses in related technical fields within engineering, math, the physical sciences, and the analytical biological sciences. The School of Electrical and Computer Engineering offers more than 30 courses that are commonly taken as electives by undergraduates.

## Academic Standards

Majors in electrical and computer engineering are expected to meet the following academic standards:

1. GPA ≥ 2.3 every semester.
2. At least C– in all courses used to satisfy degree requirements in the major or that serve as a prerequisite for a subsequent electrical and computer engineering course.
3. Satisfactory completion of MATH 294, PHYS 214, and two of ENGRD/ECE 210, ECE 220, and ENGRD 230 by the end of the sophomore year and adequate progress toward the degree in subsequent semesters.

## Electrical and Computer Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

Students must apply during the first three weeks of the sixth semester. They must achieve a B or better for all courses taken.

A 3.50 cumulative GPA is required upon application and must be maintained until graduation.

### Honors Seminar

Prospective honors students must take an honors seminar in the spring semester of their junior year, for a letter grade. The 2-credit honors seminar consists of a weekly series of introductory research lectures by ECE faculty members. Each honors seminar enrollee will write two short papers on topics covered in the lecture series. Many ECE faculty members will give a lecture or short series of lectures as part of the Honors Seminar.

### Honors Project

A student in the honors program is required to accumulate at least 3 credit hours from a senior year honors project with an ECE faculty member, consisting of either design, research, or directed reading at the 400 level. All honors projects emphasize the development of communication skills. Design- and reading-oriented honors projects explicitly require a written submission summarizing and concluding the project.

### Additional Course Work

At least 3 credit hours are required of advanced (senior level) ECE course work that has at least a 300-level prerequisite. These credit hours are in addition to any credit hours required as part of the ECE major.

The requirement for at least 9 credits over and above the 128 credits required for a B.S. degree means that an honors degree requires ≥ 137 credit hours.

# ENGINEERING PHYSICS

Offered by the School of Applied and Engineering Physics

Contact: 212 Clark Hall, 255–5198, www.aep.cornell.edu

The Engineering Physics (EP) major is designed for students who want to pursue careers of research or development in applied science or advanced technology and engineering. Its distinguishing feature is a focus on the physics and math fundamentals, both experimental and theoretical, that are at the base of modern engineering and research and have a broad applicability in these areas. By choosing areas of concentration, the students may combine this physics base with a good background in a conventional area of engineering or applied science.

The industrial demand for EP B.S. graduates is high, and many students go directly to industrial positions where they work in a variety of areas that either combine, or are in the realm of, various more conventional areas of engineering. Recent examples include bioengineering, computer technology, electronic-circuit and instrumentation design, energy conversion, environmental engineering, geological analysis, laser and optical technology, microwave technology, nuclear technology, software engineering, solid-state-device development, technical management, and financial consulting. A number of our graduates go on for advanced study in all areas of basic and applied physics as well as in a diverse range of areas in advanced science and engineering. Examples include applied physics, astrophysics, atmospheric sciences, biophysics, cell biology, computer science and engineering, electrical engineering, environmental science, fluid mechanics, geotechnology, laser optics, materials science and engineering, mathematics, mechanical engineering, medical physics, medicine, nuclear engineering, oceanography, and physics. The major can also serve as an excellent preparation for medical school, business school, or specialization in patent law.

The EP major fosters this breadth of opportunity because it both stresses the fundamentals of science and engineering and gives the student direct exposure to the application of these fundamentals. Laboratory experimentation is emphasized, and ample opportunity for innovative design is provided. Examples are ENGRI/A&EP 110, Lasers and Photonics; ENGRI/A&EP 102, Introduction to Nanoscience and Nanoengineering; ENGRD/A&EP 264, Computer-Instrumentation Design (a recommended sophomore engineering distribution course); A&EP 330, Modern Experimental Optics (a junior/senior course); A&EP 363, Electronic Circuits (a sophomore/junior course); PHYS 410, Advanced Experimental Physics; and A&EP 438, Computational Engineering Physics (a senior computer laboratory).

Students who plan to affiliate with the EP major are advised to arrange their Common Curriculum with their developing career goals in mind. They are encouraged to take PHYS 112 or 116 during their first semester (if their advanced placement credits permit) and are recommended to satisfy the technical writing requirement with the engineering distribution course ENGRD 264. EP students need to take only one engineering distribution course, since A&EP 333, taken in the junior year, counts as the second one. EP students are advised to take A&EP 363 (taking ECE 210 and 230, 4 credits each, can satisfy AEP 363. Count ECE 210 as an approved elective and ECE 230 as AEP 363) in the spring semester of the sophomore year. Students with one semester of advanced placement in math and who have received at least A- in MATH 192 may wish to explore accelerating their math requirements so as to enroll in A&EP 321 and 322 in the sophomore year. For advice on this option, consult with the A&EP associate director.

In addition to the requirements of the Engineering Common Curriculum,* the major requirements are as follows:

| *Course* | *Credits* |
|---|---|
| A&EP 333, Mechanics of Particles and Solid Bodies | 4 |
| A&EP 355, Intermediate Electromagnetism | 4 |
| A&EP 356, Intermediate Electrodynamics | 4 |
| A&EP 361, Introductory Quantum Mechanics | 4 |
| A&EP 363, Electronic Circuits | 4 |
| A&EP 423, Statistical Thermodynamics | 4 |
| A&EP 434, Continuum Physics | 4 |
| PHYS 410, Advanced Experimental Physics | 4 |
| A&EP 321, Mathematical Physics I; or | |
| MATH 421 (applied mathematics) | 4 |
| A&EP 322, Mathematical Physics II; or | |
| MATH 422 (applied mathematics) | 4 |

Six major-approved electives (18–23 credits), of which five must be technical upper-level courses (300 or above).

Total major credits=58 credit hours minimum

*The Engineering Common Curriculum allows freshmen to take only four courses each semester. This course load is fully consistent with the requirements of the EP major, but freshmen with strong preparation are encouraged to consider taking an additional course during one or both semesters so that they may have additional flexibility in developing a strong, individualized educational program in their later years and for allowing options such as a semester or year abroad or early graduation.

Two of the 4 credits of PHYS 410 required for the B.S. degree in EP can be satisfied by completing A&EP/PHYS 330 or ASTRO 410. The remaining 2 credits of PHYS 410 can then be satisfied by taking PHYS 400 for 2 credits, provided that the experiments completed in PHYS 400 do not overlap with those in A&EP/PHYS 330 or ASTRO 410. (A list of experiments that are not appropriate will be prepared by A&EP faculty and made available in the A&EP office.) If a student chooses this option, A&EP/PHYS 330 or ASTRO 410 may also count as a technical elective, provided the remaining three technical electives are 4 credits each.

**Choosing elective courses.** The EP major provides the students with a strong opportunity to develop individualized programs of study to meet their particular educational and career goals. These can include the pursuit of a dual major or the development of a broad expertise in a number of advanced technical and scientific areas. With at least seven electives in the sophomore, junior, and senior years, EP majors are encouraged to work closely with their adviser to develop a coherent academic program that is in accordance with those goals. For students who look toward an industrial position after graduation, the electives should be chosen to widen their background in a specific area of practical engineering. A different set of electives can be selected as preparation for medical, law, or business school. For students who plan on graduate studies, the electives provide an excellent opportunity to explore upper-level and graduate courses and to prepare themselves particularly well for graduate study in any one of a number of fields. Various programs are described in a special brochure available from the School of A&EP, Clark Hall. Students are advised to consult with their EP adviser, a professor active in their area of interest, or with the associate director of the school.

Electives need not be all formal course work: qualified students are encouraged to undertake independent study under the direction of a member of the faculty (A&EP 490). This may include research or design projects in areas in which faculty members are active.

The variety of course offerings and many electives provide flexibility in scheduling. If scheduling conflicts arise, the school may allow substitution of courses nearly equivalent to the listed required courses.

#### Academic Standing

Students are expected to pass every course in which they are registered, to earn at least C- in specifically required courses, and to attain a semester GPA ≥ 2.3 each semester.

### Engineering Physics Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate majors" as well as the following requirements.

1. At least 8 credits of major-approved electives at the 400 level or higher with at least A- in each, not counting credits given for item 2.
2. Two semesters of A&EP 490 or an equivalent course, with at least 2 credits the first semester and 4 credits the second. The student will complete an independent research project or senior thesis under the supervision of an engineering or science faculty member. The level of work required for successful completion is to be consistent with the amount of academic credit granted.

#### Procedures

Before enrolling in A&EP 490 or the equivalent, the honors candidate must submit a brief proposal outlining the topic and scope of the project or thesis and an honors adviser's written concurrence to the associate director for undergraduate studies. This proposal will be reviewed by the A&EP Honors Committee and either approved or returned to the candidate to correct deficiencies. The proposed project or thesis is to consist of a research, development, or design project and must go beyond a literature search. The final steps in completing the honors project are a written and oral report. The written report is to be in the form of a technical paper with, for example, an abstract, introduction, methods section, results section, conclusions section, references, and figures. This report will be evaluated by the faculty supervisor and the chair of the A&EP Honors Committee. Following completion of the written report, an oral report is to be presented to an audience consisting of the faculty supervisor, the chair of the Honors Committee, and at least one other departmental faculty member, along with the other honors candidates. The final research project course grade will be assigned by the faculty supervisor after consultation with the chair of the Honors Committee. At least A- is required for successful completion of the honors requirement.

## ENVIRONMENTAL ENGINEERING

To be offered by the School of Civil and Environmental Engineering, pending final approval. A joint offering of this major in the Department of Biological and Environmental Engineering is planned. Until final approval, environmental engineering is offered as a concentration within the existing majors of civil engineering and biological and environmental engineering.

Contact: 221 Hollister Hall, 255–3142, www.cee.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET) under the title "Civil Engineering."

Environmental engineering is the study and practice of analyzing, designing, and managing natural and engineered systems in ways consistent with the maintenance or enhancement of environmental quality and sustainability. It requires the ability to predict multiple interactions and impacts among natural and engineering-system components at various spatial and temporal scales in response to alternative design and management policies. It requires increased understanding of the interactions among the natural environment, the constructed environment, and human activities.

The major requires a GPA ≥ 2.0 in engineering and science courses, and at least a C- in ENGRD 202, CHEM 257, or ENGRD 251.

Students planning to affiliate with this major should take the following courses:

**Mathematics-science requirements**

MATH 191, 192, 293, 294

PHYS 112, 213

CHEM 207, 257*

CS100 or BEE 151 (computer programming)

**Introduction to engineering**

ENGRI 113 recommended

**Engineering distribution courses**

| | |
|---|---|
| ENGRD 251, Engineering for a Sustainable World, is required. | 3 |
| ENGRD 202, 241, or CEE 304 are recommended. | 3–4 |

**Major-required courses**

| *Major Courses* | | *Credits* |
|---|---|---|
| BIO G 10X | Introductory Biology (BIO G 101/103, 105, 107, 109, or 110) | 3–4 |
| ENGRD 202 | Mechanics of Solids | 4 |
| ENGRD 241 | Engineering Computation** | 3 |
| CEE 304 | Uncertainty Analysis in Engineering | 4 |
| CEE 323 | Engineering Economics and Management | 3 |
| CEE 331 | Fluid Mechanics | 4 |
| CEE 341 | Introduction to Geotechnical Engineering and Analysis | 4 |
| CEE 351 | Environmental Quality Engineering | 3 |
| CEE 451 | Microbiology for Environmental Engineering | 3 |
| Lab course | CEE 453 (fall), BEE 427 (fall), or CEE 437 (every other spring) | 3 |
| BEE 475 | Environmental Systems Analysis | 3 |

**Electives**

| | |
|---|---|
| Technical communications course (ENGRC 335, 350; COMM 260, 263, 252; CEE 453; or BEE 489) | 3–4 |
| Three CEE design electives*** | 9–12 |
| One major-approved elective††† | 6–8 |
| Two approved electives | 6 |
| Total credits (minimum) | 127 |

*Substitute CHEM 357 for 257, without petition

‡Students using this course as a second engineering distribution must take an additional elective. BIO G 109–110 is not an engineering distribution course.

** If ENGRD 241 is not taken as a distribution course, it must be taken as a major-approved elective.

# Students planning graduate-level study in EnvE may take BIOMI 290, Introduction to Microbiology, in place of CEE 451.

***To be chosen from a list of design courses. Students are encouraged to take CEE 352.

## The list of suggested courses covers the areas of environmental engineering, hydraulics/hydrology, environmental systems engineering, geotechnical engineering, remote sensing, air pollution, and biological and environmental engineering. The list is available at the departmental office.

****If the course fulfilling the technical writing requirement also fulfills another requirement (e.g., liberal studies, major-approved elective), then an additional approved elective must be substituted for this requirement.

## Environmental Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

The 9 credits beyond the B.S. requirements shall be drawn from one or more of the following components:

1. A research experience or honors project under the direct supervision of a faculty member using CEE 400, Senior Honors Thesis (1–6 credits per semester). A significant written report or senior honors thesis must be submitted as part of this component.
2. A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the College of Engineering, i.e., ENGRG 470, Peer Teaching in Engineering, or CEE 401, Undergraduate Teaching in CEE (1–3 credits per/semester).
3. Courses at the 500 level or above. At least 2 credits in any component of the program.

### Procedures

Each program must be approved by the CEE Curriculum Committee (the committee may delegate approval authority to the associate director for all but unusual proposals).

# GEOLOGICAL SCIENCES

Offered by the Department of Earth and Atmospheric Sciences

Contact: 2124 Snee Hall, 255-5466, www.eas.cornell.edu

We live on a planet with finite resources and a finite capacity to recover quickly from human-induced environmental stresses. It is a naturally powerful planet, with natural hazards such as earthquakes, hurricanes, and volcanic eruptions that alter the course of history with little prior warning. As the human population grows, understanding the earth and its resources becomes progressively more important to both future policymakers and ordinary citizens, who must find new sources of energy and sustain the quality of our environment. Because the human need to understand the earth is so pervasive and the earth system is so multifaceted, the major has three options, which cover the spectrum of modern earth sciences.

The three options are the geoscience option, the atmospheric science option, and the science of earth systems (SES) option. The geoscience option emphasizes the structure, composition, and evolution of our planet; the atmospheric science option covers the planetary processes producing weather and climate; and the SES option is concerned with processes on and near the earth's surface where the interactions of water, life, rock, and air produce our planetary environment.

## Geoscience Option

The geoscience option reveals Earth's turbulent history from the formation of our solar system to the plate tectonic cycles and ice ages that dominate Earth's present behavior. That history is highlighted by the co-evolution of life and the Earth system—from the origin of life to the modern interglacial phase during which our species has proliferated and become able to alter the chemical and physical environment. Topics of study also include the fundamental processes responsible for earthquakes, volcanic eruptions, and mountain building. This option prepares students for advanced study in geology, geophysics, geochemistry, and geobiology and for careers in energy and mineral industries or in water and contaminant investigation (environmental geology). The option is also valuable for a pre-law or pre-med program or in preparation for a career in K–12 education.

The geoscience option stresses a balanced overview of geology with considerable flexibility and a degree of specialization achieved by careful selection of major-approved electives. Students must take ENGRD/EAS 201 as an engineering distribution course. For students interested in geobiology or paleontology, BIO G 101/103–102/104 (or BIO G 109–110) are recommended. CHEM 208 may be substituted for PHYS 214. Learning through direct observation of the natural system is highly valued, akin to design projects in other engineering majors.

The geoscience option requires these courses: the introductory outdoor field course EAS 210 and the five core courses EAS 326, 355, 356, 375, and 388. Two additional EAS major-required courses and at least one major-approved elective must be EAS 300 through 600-level courses. The core courses may be taken in any reasonable sequence, except that EAS 355 (fall course) should be taken before EAS 356 (spring course). EAS 326, 355, 356, and 375 should be taken relatively early in the program.

There are four alternatives for completing the required 4-credit advanced outdoor field experience: a) EAS 417 (Field Mapping in Argentina, 3 credits) and EAS 491–492 (1 credit based on field observations), b) EAS 437 (Geophysical Field Methods, 3 credits) plus at least 1 credit of EAS 491 or 492 using geophysical techniques from EAS 437; c) EAS 491–492 (Undergraduate Research, 2 credits each) with a significant component of fieldwork; d) a pre-approved outdoor advanced field course taught by another college or university (≥ 4 credits).

A selection of major-approved electives may provide specializations in geophysics, geochemistry (including petrology and mineralogy), geobiology (paleontology), and geology applied to mineral and petroleum industries, environmental problems, hydrology, and civil engineering. Students who want a more general background or want to remain uncommitted with regard to specialty must choose at least two of their major-approved electives from the same department or school. The major-approved electives outside the major may be chosen from offerings in other science or engineering areas or the liberal arts at the 300 level or above. Students may request substitution of EAS 491 and 492, Undergraduate Research, for a fourth-year major-approved elective but not if it is being used to fulfill the outdoor field requirement.

In addition to course work, students learn by involvement in research projects. Facilities include equipment for processing seismic signals and digital images of the Earth's surface, instruments for highly precise isotope and element analyses, and extensive libraries of earthquake records, satellite images, and exploration seismic records. Undergraduates have served as field assistants for faculty members and graduate students in South America, Europe, Asia, Canada, the USA, and several ocean islands. Undergraduates are encouraged to participate in research activities, frequently as paid assistants.

### Atmospheric Science Option

Atmospheric science is the study of the atmosphere and the processes that shape weather and climate. The curriculum emphasizes the scientific study of the behavior of weather and climate, and applications to the important practical problems of weather forecasting and climate prediction. Students develop a fundamental understanding of atmospheric processes and acquire skill and experience in the analysis, interpretation, and forecasting of meteorological events. This option satisfies both the curricular guidelines of the American Meteorological Society and the educational requirements of the National Weather Service for employment as a meteorologist, which also qualifies graduates for positions in private-sector forecasting and environmental consulting firms. The option also provides excellent preparation for graduate work in atmospheric science and related fields.

The atmospheric science option requires ENGRD 270 as an engineering distribution course as well as introductory courses in atmospheric science (EAS 131 and 133) and EAS 250 (Observations and Instrumentation). Many of the upper-division major courses require EAS 341 (Atmospheric Thermodynamics and Hydrostatics) and EAS 342 (Atmospheric Dynamics) as prerequisites, which are normally taken in the junior year. The additional required major courses are EAS 331 (Climate Dynamics), EAS 352 (Synoptic Meteorology I), EAS 451 (Synoptic Meteorology II), EAS 435 (Statistical Methods in Meteorology), and EAS 447 (Physical Meteorology). Major-approved electives may be chosen from EAS courses and selected upper-division courses in other departments.

### Science of Earth Systems (SES) Option

The SES option provides an integrated view of Earth processes critical to the understanding of our environment. This scientific understanding is the primary foundation used to determine to what degree human societies can modify or adapt to future change. The option is for students interested in careers or graduate study in any of the Earth system sciences or a future in environmental law, environmental engineering, science teaching, or environmental public policy. The option is part of the multidisciplinary, intercollege program in the Science of Earth Systems. Collaborations with other departments provide breadth and depth to the program.

The SES option emphasizes a strong preparation in basic math and sciences and an integrated approach to the study of the Earth system including the lithosphere, biosphere, hydrosphere, and atmosphere.

Students are required to take a second semester of chemistry (CHEM 208), three semesters of biology (BIO G 101/103–102/104 or BIO G 109–100; plus BIOEE 261), and ENGRD 201 (Physics and Chemistry of the Earth) as an engineering distribution course. The option requires a set of three core courses, normally taken in the junior or senior years, that provide breadth and integration. Five additional intermediate to advanced courses are selected—with the adviser's approval—to provide depth and a degree of specialization, and an additional major-approved elective is selected. These courses permit the student to specialize in such areas as climate dynamics, biogeochemistry, ocean sciences, environmental geosciences, ecological systems, hydrological sciences, and soil sciences.

Two of the specialization courses will count as major-required courses and three as major-approved electives. At least three of the major-approved electives must be non-EAS courses. The three SES core courses are:

EAS 302 Evolution of the Earth System—spring, 4 credits

EAS 321 Biogeochemistry (also NTRES 321)—fall, 4 credits

EAS 331 Climate Dynamics (also ASTRO 331)—fall, 4 credits

See www.eas.cornell.edu for possible specializations.

Excellent opportunities for learning through direct observation of the natural systems exist in either the spring "Environmental Semester in Hawaii" or through a summer field course in geology operated in Argentina (EAS 417), or through campus-based field courses.

#### Field Study in Hawaii

Field study is a fundamental aspect of earth system science. Students wishing to increase their field experience may fulfill some of the requirements for the SES major by off-campus study through the Cornell Earth and Environmental Semester program (EES). The EES program, offered during the spring semester, emphasizes field-based education and research. It is based on the island of Hawaii, an outstanding natural laboratory for earth and environmental sciences. Courses that may be applied to the SES major include EAS 240, 322, and 351. EAS 322 and 351 may also be used to fulfill requirements of the Geological Sciences major. The EES program also offers opportunities for internships with various academic, nonprofit, and government organizations. Typically, students participate in the EES program during their junior year, although exceptions are possible. The EES program is administered by Cornell Abroad. For further information, see www.geo.cornell.edu/geology/classes/hawaii/course.html.

### Geological Sciences Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate majors" as well as the following requirements.

1. Acceptance of the written proposal of the honors project by the faculty adviser, the honors adviser, and the director of undergraduate studies.
2. An honors thesis involving research (EAS 491–492 or 499, 2 or more credits each) of breadth, depth, and quality is required.

## INDEPENDENT MAJOR

Offered by the Independent Major Committee

Contact: Engineering Advising, 167 Olin Hall, 255–7414

The Independent Major is designed for students whose educational objectives cannot be met by one of the regular majors. With the exception of certain faculty-sponsored programs, this major consists of an engineering major subject (approx. 32 credits) and an educationally related minor subject (approx. 16 credits). The major may be in any subject area offered by schools or departments of the college; the minor may be in a second engineering subject area or in a logically connected nonengineering area. The combination must form an engineering education in scope and substance and should include engineering design and synthesis as well as engineering sciences. Each program includes the normally required common-curriculum requirements and approved electives.

Students should apply to the Independent Major during the sophomore year. A student should seek assistance in developing a coherent program from professors in the proposed major and minor subject areas (an adviser in each area is required). The program must also be approved by the Independent Major Committee. If approved, the program is the curricular contract to which the student must adhere.

Because no single standardized curriculum exists, the Independent Major is not accredited. Independent Major students who intend to seek legal licensing as a Professional Engineer should be aware that this nonaccredited degree program will require additional education, work, and/or experience to qualify for eligibility to take the Fundamentals of Engineering examination and may affect acceptance into engineering graduate programs.

# INFORMATION SCIENCE, SYSTEMS, AND TECHNOLOGY

Offered jointly by the Department of Computer Science and the School of Operations Research and Industrial Engineering

Contact: 303 Upson Hall, 255–9837, www.infosci.cornell.edu, and 202 Rhodes Hall, 255–5088, www.orie.cornell.edu

Digital information technologies have become pervasive in science, engineering, manufacturing, business, finance, culture, law, and government, dramatically changing the way people work and live. The proliferation and significance of these new technologies demands a new focus in engineering education—one that remains rigorous and technically oriented but is simultaneously devoted to integrating engineering design, theory, and practice within the social and organizational contexts in which these complex digital information systems are employed.

The ISST major studies the design and management of complex information systems. Just as structural engineers and nanofabricators use physics at radically different scales, so also there is a scale difference between the focus of the ISST major and the more traditional, look-under-the-hood majors in computer science and operations research and industrial engineering. Rather than focusing on the computing and communication technologies that underlie digital information systems, the ISST major emphasizes information systems engineering in broad application contexts, where issues at the confluence of information science, technology, and management are the primary concerns.

The ISST major has two options. Students in the Management Science option will obtain advanced training in quantitatively oriented decision making in the information technology arena. Students in the Information Science option will obtain advanced training in methods for the creation, representation, organization, access, and analysis of information in digital form.

**Engineering distribution courses**

Majors are required to take ENGRD 270, Basic Engineering Probability and Statistics as an engineering distribution course. ENGRD 211, Computers and Programming, is required for the major and is recommended as the second engineering distribution course.

**Major program**

| *Core courses* | *Credits* |
|---|---|
| ORIE 320, Optimization I | 3 |
| ORIE 360, Engineering Probability and Statistics II | 3 |
| INFO 230, Intermediate Design and Programming for the Web | 3 |
| ORIE 311, Information Systems and Analysis | 3 |
| INFO 330, Applied Database Systems | 3 |
| ECON 301 or 313, Microeconomics | 3 |
| One of: | |
| ILROB 170, Introduction to Micro Organizational Behavior and Analysis | 3 |
| INFO 245, Psychology of Social Computing | 3 |

**Requirements for the Information Science option:**

1. Three courses from Information Systems (Area II below).
2. One course from Mathematical Modeling in IT (Area III).
3. Three electives, all from either Human-Centered Systems (Area V) or Social Systems (Area VI).
4. Two electives from any of the six areas.

**Requirements for the Management Science option:**

1. Four courses from Mathematical Models in Management Science (Area I).
2. Three electives, one from each of
   - Information Systems (Area II)
   - Mathematical Modeling in IT (Area III)
   - Information Technology Management Solutions (Area IV)
3. Two electives from any of the six areas.

**Area I. Mathematical Models in Management Science**

ORIE 350 Financial and Managerial Accounting

ORIE 361 Introductory Engineering Stochastic Processes I

ORIE 480 Information Technology

ORIE 580 Simulation Modeling and Analysis

**Area II. Information Systems**

INFO 430 Information Retrieval

INFO 431 Web Information Systems

COM S 432 Introduction to Database Systems

COM S 465 Computer Graphics I

COM S 472 Foundations of Artificial Intelligence

COM S 474 Introduction to Natural Language Processing

COM S 501 Software Engineering

COM S 578 Empirical Methods in Machine Learning and Data Mining

**AREA III. Mathematical Modeling in IT**

OR&IE 431 Discrete Models

OR&IE 464 Extreme Value Analysis with Applications to Finance and Data Communications

OR&IE 474 Statistical Data Mining I

COM S 478 Machine Learning

OR&IE 483 Applications of Operations Research and Game Theory to IT

ECE 562 Fundamental Information Theory

OR&IE 574 Statistical Data Mining II

**Area IV. IT Management Solutions**

OR&IE 481 Delivering OR Solutions with Information Technology

OR&IE 518 Supply Chain Management

**Area V. Human-Centered Systems**

PSYCH/COGST 342 Human Perceptions: Applications to Computer Graphics, Art, Visual Display*

INFO 345 Human-Computer Interaction Design

PSYCH 347 Psychology of Visual Communications

PSYCH 380 Social Cognition*

PSYCH 413 Information Processing: Conscious and Unconscious

PSYCH/COGST 416 Modeling Perception and Cognition*

INFO 440 Advanced Human-Computer Interaction Design

INFO 450 Language and Technology

DEA 470 Applied Ergonomic Methods

* Students who take PSYCH 342 or 416 may also count their prerequisite, PSYCH 205 or 214. Students who take PSYCH 380 may also count PSYCH 280. At most one of these 200-level prerequisites can be counted.

**Area VI. Social Systems**

SOC 304 Social Networks and Social Processes

AEM 322 Technology, Information, and Business Strategy

INFO 349 Media Technologies

INFO 355 Computers: From Babbage to Gates

ECON 368 Game Theory*

INFO 387 The Automatic Lifestyle: Consumer Culture and Technology

ECON 404 Economics and the Law

LAW 410 Limits on and Protection of Creative Expressions—Copyright Law

STS 411 Knowledge, Technology, and Property

ECON 419 Economic Decisions Under Uncertainty

COMM 428 Communication Law

INFO 435 Seminar on Applications in Information Science

ORIE 435 Introduction to Game Theory*

STS 438 Minds, Machines, and Intelligence

INFO 447 Social and Economic Data

ECON 476/477 Decision Theory I and II

INFO 515 Culture, Law, and Politics of the Internet

* Only one of ECON 368 and ORIE 435 can be taken for ISST credit.

## Information Science, Systems, and Technology Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

1. 8 credit hours of ISST course work at or above the 500 level (no SU courses; no seminars or 2-credit courses)
2. 6 credit hours of INFO 490 independent study and research with an ISST faculty member, spread over at least two semesters and with at least A- each semester

   OR

   3 credit hours of INFO 490 independent study and research with an ISST faculty member and 3 credit hours of INFO 491 teaching experience, both with grades of at least A-

The ISST research is expected to result in a programming project or a written report (or both).

Any 500- or 600-level course taken to fulfill the honors requirements may be counted toward fulfillment of the associated primary or secondary option requirements.

**Procedures**

Each program must be approved by the appropriate co-director of the ISST major, and any changes to the student's program must also be approved.

**Note:** Students will not be allowed to double major in ISST and COM S or ISST and OR&IE.

## MATERIALS SCIENCE AND ENGINEERING

Offered by the Department of Materials Science and Engineering

Contact: 214 Bard Hall, 255–4135, www.mse.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Prospective majors are required to take ENGRD 261 or ENGRD 262 before affiliating with the major. It is strongly recommended that the course be taken as engineering distribution during the sophomore year. The major program develops a comprehensive understanding of the physics and chemistry underlying the unique properties of modern engineering materials and processes.

Students are required to complete a series of electives to develop knowledge of materials, such as biomaterials, ceramics, polymers, and semiconductors. Application-related courses include the areas of biotechnology and life science, energy and environment, materials for information science, nanotechnology, and technology management and ethics. These requirements are satisfied through a series of technical electives taken mainly in the senior year, selected from various engineering and science departments. Optional research involvement courses provide undergraduates with the opportunity to work with faculty members and their research groups on current projects.

The major requirements for a B.S. degree in materials science and engineering are:

1. ENGRD 261, Mechanical Properties of Materials: From Nanodevices to Superstructures OR

   ENGRD 262, Electronic Materials for the Information Age
2. 12 required major courses:

   MS&E 204 Materials Chemistry

   MS&E 206 Atomic and Molecular Structure of Matter

   MS&E 302 Mechanical Properties of Materials, Processing, and Design

   MS&E 303 Thermodynamics of Condensed Systems

   MS&E 304 Kinetics, Diffusion, and Phase Transformations

   MS&E 305 Electronic, Magnetic, and Dielectric Properties of Materials

   MS&E 307 Materials Design Concepts I

   MS&E 311 Junior Lab I

   MS&E 312 Junior Lab II

   MS&E 403/405 Senior Materials Lab I or Senior Thesis I

   MS&E 404/406 Senior Materials Lab II or Senior Thesis II

   MS&E 407 Materials Design Concepts II
3. Two materials-related electives covering two groups of different materials
4. Three application-related electives in at least two different types of applications
5. Two of the application-related electives must be taken from outside MS&E
6. One additional technical elective outside MS&E

### Materials Science and Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

1. The 9 credits (giving a total of 140) of additional courses must be technical in nature, i.e., in engineering, math, chemistry, and physics at the 400 and graduate level, with selected courses at the 300 level. The courses must be approved by the major adviser.
2. Senior honors thesis (MS&E 405/406) with a grade of at least A.

## MECHANICAL ENGINEERING

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 108 Upson Hall, 255–3573, www.mae.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

This major is designed to provide a broad background in the fundamentals of the discipline as well as to offer an introduction to the many professional and technical areas with which mechanical engineers are concerned. The program covers both major streams of mechanical engineering.

*Mechanical systems, design, and materials processing* is concerned with the design, analysis, testing, and manufacture of machinery, vehicles, devices, and systems. Other topics covered are computer-aided design, vibrations, control systems, and dynamics. Particular areas of concentration are mechanical systems and design, vehicle engineering, biomechanics, and engineering materials.

*Engineering of fluids, energy, and heat-transfer systems* is concerned with the efficient conversion of energy, aerospace and surface transportation, the environmental impact of engineering activity (including pollutants and noise), aeronautics, and the experimental and theoretical aspects of fluid flow, heat transfer, thermodynamics, and combustion. Specific areas of concentration include aerospace engineering and thermo-fluids engineering.

During the fall term, sophomores who plan to affiliate with the Mechanical Engineering major take ENGRD 202 (also T&AM 202) as an engineering distribution course. ENGRD 221/M&AE 221 is required for the major and is recommended as the second engineering distribution course. The Sibley School supports students who have unusual requirements, but delays or substitutions must be discussed with and receive approval of their major adviser.

The major requires eleven courses (beyond ENGRD 202 already mentioned) and five major-approved elective courses.

**Required courses**

M&AE 212, Mechanical Properties and Selection of Engineering Materials

ENGRD 221, Thermodynamics

M&AE 225, Mechanical Design and Synthesis

ENGRD 203, Dynamics

ECE 210, Introduction to Circuits for Electrical and Computer Engineers (PHYS 360 or M&AE 378 may be substituted)

M&AE 323, Introductory Fluid Mechanics

M&AE 324, Heat Transfer

M&AE 325, Analysis of Mechanical and Aerospace Structures

M&AE 326, System Dynamics

M&AE 327, Mechanical Property and Performance Laboratory

M&AE 427, Fluids/Heat Transfer Laboratory

M&AE 428, Seminar on Engineering Design

**Electives**

Students should use the flexibility provided by the major-approved electives, adviser-approved electives, and humanities/social sciences electives to develop a program to meet their specific goals.

**Major-approved electives**

The major includes five major-approved electives. At least three of these courses must be upper-level (300+) M&AE courses. Of these three, two must be a concentration of MA&E's upper-level courses. Standard concentrations are shown below, but students may petition for approval of two other related courses to form a custom concentration.

The standard concentrations are:

Aerospace Engineering, M&AE 305, 306, 415, 423, 506, 507

Biomechanics, M&AE 463, 464, 466, 565

Engineering Materials, M&AE 312, 313, 455, 464, 470, 513

Mechanical Systems and Design, M&AE 378*, 409, 415, 417, 470, 477, 478, 479, 514, 525

Thermo-Fluids Engineering, M&AE 423, 449, 453, 501, 543

Vehicle Engineering, M&AE, 305, 306, 386, 425, 440, 449, 506, 507

*Students substituting M&AE 378 for the required ECE 210 cannot use M&AE 378 as a major-approved elective.

Of the three upper-level M&AE courses, one must be an approved design elective. The design offerings may change from year to year. Typically, they include M&AE 401, 412, 426, 441, 470, 479, 486, 491, and 525.

The design elective must be taken during the senior year. A single course may satisfy both the design and concentration requirements, in which case the third course could be any upper-level M&AE course.

One of the courses must be an approved upper-level math course taken after MATH 294. The course must include some statistics. Currently, the approved courses are T&AM 310, OR&IE 270, and CEE 304.

One of the major-approved electives may be any course at an appropriate level, chosen from engineering, math, or science (physics, chemistry, or biological sciences). Appropriate level is interpreted as being at a level beyond the required courses of the college curriculum. Courses in economics, business, and organizational behavior are not accepted. Advisers may approve such courses as adviser-approved electives.

**Adviser-approved electives**

To maximize flexibility (i.e., the option for study abroad, COOP, internships, pre-med, and flexibility during the upperclass years), the Sibley School faculty recommends that students delay use of adviser-approved (AA) electives until after term three. Students must seek adviser approval before taking an AA elective. Advanced placement credit cannot count as an AA elective, nor can Reserve Officer Training Corps (ROTC) courses unless they are co-listed in an academic department. Students must document AA electives approved before M&AE affiliation within a month of registration as an M&AE student. The faculty encourages students to consider the following as possible AA electives:

- an engineering distribution course
- courses stressing oral or written communications
- courses stressing the history of technology
- rigorous courses in the physical sciences (physics, biology, chemistry)
- courses in information science (mathematics, computer science)
- courses in methodologies (modeling, problem solving, synthesis, design)
- courses in technology (equipment, machinery, instruments, devices, processes)
- courses in business enterprise operations (e.g., economics, financial, legal)
- courses in organizational behavior
- courses in cognitive sciences

**Other considerations**

It is recommended that humanities/social sciences electives include studies in:

- history of technology
- societal impacts of technology
- history
- foreign languages
- ethics
- communications
- political science
- aesthetics
- economics
- architecture

The technical-writing requirement of the Common Curriculum is satisfied by M&AE 427.

Introduction to Circuits for Electrical and Computer Engineers (ECE 210) may be replaced or supplemented by Electronic Circuits (PHYS 360) or Mechatronics (M&AE 378).

A limited set of third-year courses is offered each summer under the auspices of the Engineering Cooperative Program.

**Preparation in Aerospace Engineering**

There is no separate undergraduate program in aerospace engineering, but students may prepare for a career in this area by majoring in mechanical engineering and taking courses from the aerospace engineering concentration. Students may prepare for the graduate program in aerospace engineering by majoring in mechanical engineering, in other appropriate engineering specialties such as electrical engineering or engineering physics, or in the physical sciences. Other subjects recommended as preparation for graduate study include thermodynamics, fluid mechanics, applied mathematics, chemistry, and physics.

## OPERATIONS RESEARCH AND ENGINEERING

Offered by the School of Operations Research and Industrial Engineering

Contact: 202 Rhodes Hall, 255-5088, www.orie.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

This major provides a broad education in the techniques and modeling concepts needed to analyze and design complex systems and to provide an introduction to the technical and professional areas with which operations researchers and industrial engineers are concerned. The major prepares students for a wide range of careers including operations research, industrial engineering, entrepreneurship, information technology, operations management, consulting, financial engineering, financial services, and management.

The foundation of the major is the development of basic skills in calculus, statistics, probability, mathematical programming, and computer science. Required courses in manufacturing systems, cost accounting, and simulation build on these skills and provide engineering design experiences. In the senior year the curriculum is quite flexible. Students take OR&IE electives to broaden and deepen their expertise in applied probability and statistics, industrial systems, optimization, information technology, or financial engineering.

Because of the wide range of career goals among our students, the major is designed with a minimum of required courses and a large number of required electives. Students should consult with their major advisers to select electives that best meet their future goals.

Exceptional students interested in pursuing graduate studies are encouraged to speak with their faculty advisers concerning an accelerated program of study.

A student who intends to affiliate with the major in Operations Research and Engineering should take Basic Engineering Probability and Statistics (ENGRD 270) after completing MATH 192. Early consultation with a faculty member or the associate director for undergraduate studies can be helpful in making appropriate choices.

The required courses for the ORE major and the typical terms in which they are taken are as follows:

| *Term 2, 3, or 4* | *Credits* |
|---|---|
| ENGRD 211, Computers and Programming | 3 |
| ENGRD 270, Basic Engineering Probability and Statistics | 3 |
| *Term 5* | |
| OR&IE 320, Optimization I | 4 |
| OR&IE 350, Financial and Managerial Accounting | 4 |
| OR&IE 360, Engineering Probability and Statistics II | 4 |
| Humanities/social sciences elective | 3 |
| Major-approved elective | 3 |
| *Term 6* | |
| OR&IE 310, Industrial Systems Analysis (may be taken in term 4) | 4 |
| OR&IE 321, Optimization II | 4 |
| OR&IE 361, Introductory Engineering Stochastic Processes I | 4 |
| Behavioral science (organizational behavior)† | 3 |
| Humanities/Social sciences elective | 3 |

†The behavioral science requirement can be satisfied by any of several courses, including the Johnson Graduate School of Management (JGSM) course NCC 554 (offered only in the fall), which is recommended for those contemplating the pursuit of a graduate business degree, ILROB 170, 171, and 320, H ADM 115, and others.

The basic senior-year program, from which individualized programs are developed, consists of the following courses:

| *Minimum credits* | |
|---|---|
| OR&IE 580, Simulation Modeling and Analysis | 4 |
| Either OR&IE 416 or OR&IE 480 (program design requirement) | 4 |
| Two upperclass OR&IE electives as described below | 5 |
| Three major-approved electives (at least 3 credits must be outside OR&IE) | 9 |
| Two humanities/social sciences electives | 6 |
| Two adviser-approved electives | 6 |

Available OR&IE electives are as follows:

Manufacturing and distribution systems: OR&IE 416, 451, 480, 481, 483, 518, 524, 525, and 562 and JGSM NBA 641

Optimization methods: OR&IE 431, 432, 434, 435, 436, and 533

Applied probability and statistics: OR&IE 462, 464, 474, 476 (2 credits), 561, 563, 574, 575 (2 credits), 576 (2 credits) and 577

Financial engineering: OR&IE 467, 468, 469, and 473.

### Academic Standing

The student in the major should obtain a passing grade in every course; at least C- in ENGRD 211 and 270, OR&IE 310, 320, 321, 350, 360, 361 and 580; a semester GPA ≥ 2.0 each semester; GPA ≥ 2.0 for ORE major courses; and satisfactory progress toward completion of the degree requirements. Each student's performance is reviewed at the conclusion of each semester.

If at least C- is not earned in a required course, the course must be repeated within one year before the next course in the sequence may be taken (OR&IE 321 and 361, in particular). Failure to achieve at least C- in the second attempt will generally result in withdrawal from the major.

### Operations Research and Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Undergraduate Majors" as well as the following requirements.

The 9 additional credits of course work shall be from one or more of the following, with at least 4 credits in the first category:

1. Advanced courses in OR&IE at the 500 level or above.
2. A significant research experience or honors project under the direct supervision of an OR&IE faculty member using OR&IE 499, OR&IE Project. A significant written report must be submitted as part of this component.
3. A significant teaching experience under the direct supervision of a faculty member in OR&IE using OR&IE 490, Teaching in OR&IE, or ENGRG 470, Undergraduate Engineering Teaching.

#### Procedures

Each program must be approved by the associate director of undergraduate studies, and any changes to a program must be approved by the associate director.

## ENGINEERING MINORS AND OPTIONS

The engineering minor is a supplement to the B.S. degree majors in the college, including the independent major. It recognizes formal study of a particular subject area in engineering normally outside the major. Students undertaking a minor are expected to complete the requirements during the time of their continuous undergraduate enrollment at Cornell. Completing the requirements for an engineering minor (along with a major) may require more than the traditional eight semesters at Cornell. In many cases, however, courses that fulfill minor requirements may also satisfy other degree requirements (e.g., distribution courses, adviser-approved, or major-approved electives), and completion within eight semesters is possible.

An engineering minor or option requires:

- successful completion of all requirements for a B.S. degree in engineering.
- enrollment in an engineering major that approves participation in the minor or option.
- satisfactory completion of six courses (at least 18 credits) in a college-approved minor (or four courses and a seminar (at least 13 credits) in the option).

Students may apply for certification of an engineering minor at any time after the required course work has been completed in accordance with published standards. An official notation of certification of a minor or option appears on the Cornell transcript following graduation.

The College of Engineering offers minors and one option in the following areas (offering units are indicated in parentheses):

Applied Mathematics (T&AM)

Biological Engineering (BEE)

Bioengineering Option (Bioengineering Program)

Biomedical Engineering (BME)

Civil Infrastructure (CEE)

Computer Science (COM S)

Electrical and Computer Engineering (ECE)

Engineering Management (CEE)

Engineering Statistics (OR&IE)

Environmental Engineering (BEE/CEE)

Geological Sciences (EAS)

Industrial Systems and Information Technology (OR&IE)

Information Science (INFO)

Materials Science and Engineering (MS&E)

Mechanical Engineering (M&AE)

Operations Research and Management Science (OR&IE)

Additional information on specific minors can be found below, in the *Engineering Undergraduate Handbook*, in the undergraduate major office of the department or school offering the minor or option, and in Engineering Advising.

## MINOR: APPLIED MATHEMATICS

Offered by the Department of Theoretical and Applied Mechanics

Contact: Richard Rand, 207 Kimball Hall, 255–7145, rhr2@cornell.edu, www.tam.cornell.edu/Undergrad.html

All engineering undergraduates are eligible to participate in this minor.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses beyond MATH 294, to be chosen as follows:

a) At most one course from any one of the groups 1, 2, 3, or 4.

b) At least three courses from groups 5 and 6.

c) At most one 200-level course.

d) At most one course that is offered by the student's major department.

1. Analysis

   T&AM 310 Advanced Engineering Analysis I

   MATH 323 Introduction to Differential Equations

   MATH 420 Differential Equations and Dynamical Systems

   A&EP 321 Mathematical Physics I

2. Computational methods

   COM S/ENGRD 322 Introduction to Scientific Computation

   CEE/ENGRD 241 Engineering Computation

   OR&IE 320 Optimization I

3. Probability and statistics

   OR&IE/ENGRD 270 Basic Engineering Probability and Statistics

   OR&IE 360 Engineering Probability and Statistics II

   ECE 310 Introduction to Probability and Random Signals

   CEE 304 Uncertainty Analysis in Engineering

   MATH 471 Basic Probability

4. Applications

   A&EP 333 Mechanics of Particles and Solid Bodies

   CHEME 323 Fluid Mechanics

   CEE 331 Fluid Mechanics

   CEE 371 Modeling of Structural Systems

   COM S 280 Discrete Structures

   ECE 425 Digital Signal Processing

   MS&E 303 Thermodynamics of Condensed Systems

   M&AE 323 Introductory Fluid Mechanics

5. Advanced courses

   At most one of these three:

   T&AM 311 Advanced Engineering Analysis II

   MATH 422 Applied Complex Analysis

   A&EP 322 Mathematical Physics II

   At most one of the following two:

   ECE 411 Random Signals

   OR&IE 361 Introductory Engineering Stochastic Processes I

   At most one of these two:

   COM S 381 Introduction to Theory of Computing

   COM S 481 Introduction to Theory of Computing

   At most one of these two:

   M&AE 571 Applied Dynamics

   T&AM 570 Intermediate Dynamics

   Any number of these:

   COM S 482 Introduction to the Design of Algorithms

   OR&IE 321 Optimization II

OR&IE 431 Discrete Models

OR&IE 435 Introduction to Game Theory

OR&IE 462 Introductory Engineering Stochastic Processes II

T&AM 578 Nonlinear Dynamics and Chaos

T&AM 610 Methods of Applied Mathematics I

T&AM 611 Methods of Applied Mathematics II

6. Mathematics courses

   Any 300+ level course offered by the Mathematics Department in algebra, analysis, probability/statistics, geometry, or logic, with the following exceptions:

1. MATH 323 or MATH 420, if any course from group 1 is chosen
2. MATH 471, if any course from group 3 is chosen
3. MATH 422, if T&AM 311 or A&EP 322 are chosen from group 5
4. Only one of the following may be chosen:

   MATH 332 Algebra and Number Theory

   MATH 335 Introduction to Cryptology

   MATH 336 Applicable Algebra

**Note:** ENGRG 605–606 and M&AE 664 are graduate courses with limited enrollment. First preference is given to graduate students.

## MINOR: BIOLOGICAL ENGINEERING

Offered by the Department of Biological and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255–2173, www.bee.cornell.edu

Students in all majors except Biological Engineering may participate. Students may participate in only the Bioengineering Option, the Biological Engineering minor, or the Biomedical Engineering minor.

Students should meet with the BE program director as soon as they decide to pursue the minor. They will receive a BEE faculty adviser, who will assist them in completing their minor.

Biological Engineering is the application of engineering to living systems. Examples of engineering efforts in this field include the development of new biosensor technologies, study and control of biologically based matter transformation systems, and development of engineered devices to study and regulate fundamental biological processes. The Biological Engineering minor is an opportunity for students to further their understanding of living systems and to increase their knowledge of the basic transport processes that occur within these systems. Courses in the minor provide opportunities to analyze and manipulate living systems at the molecular, cellular, and system levels.

**Academic standards:** At least C- in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits), as follows:

BEE 350, Biological and Environmental Transport Processes

I. Analysis: Two (2) of these:

   MS&E 304 (3) Kinetics, Diffusion, and Phase Transformations

   CHEME 313 (3) Chemical Engineering Thermodynamics

   CHEME 390 (3) Reaction Kinetics and Reactor Design

   CEE 437 (3) Experimental Methods in Fluid Dynamics

   BEE 685 (4) Biological Engineering Analysis

II. Application: Two (2) of these:

   BEE 450 (4) Bioinstrumentation

   BEE/M&AE 453 (3) Computer-Aided Engineering Applications to Biomedical Processes

   BEE 454 (3) Physiological Engineering

   BEE 459 (4) Biosensors and Bioanalytical Techniques

   BEE 655 (3) Thermodynamics and Its Applications

   CHEME 543 (3) Bioprocess Engineering

III. Basic Sciences: One (1) of these:

   BIOBM 233 (3) Introduction to Biomolecular Structure

   BIOMI 290 (3) General Microbiology

   BIOBM 330–333 (2–4) Principles of Biochemistry

   BIOBM 434 (3) Applications of Molecular Biology

   BIONB 470 (3) Biophysical Methods

## OPTION: BIOENGINEERING

Offered by the Bioengineering Program

Contact: 270 Olin Hall, 255–7577

Students in all majors, except Biological Engineering, may participate. Students may participate in only one of the Bioengineering Option, the Biological Engineering minor, and the Biomedical Engineering minor.

The purpose of the option is to provide students with a guided, coherent, individualized plan of exploration in bioengineering. Bioengineering consists of subjects that fall at the interface between engineering and life science. It involves bioprocesses, bioenvironmental engineering, biomedical devices, biomaterials, biomolecular engineering, systems biology, and more.

Students are asked to enroll after affiliation and before the beginning of the sixth semester. Enrollment requires selecting a bioengineering adviser (in addition to the major adviser), who will help select appropriate bioengineering-related courses and provide advice on careers in bioengineering.

**Academic standards:** S in the Bioengineering Seminar and at least C- in the other courses.

**Requirements**

At least 12 credit hours consisting of two to three bioengineering courses, one to two biological sciences courses, and 1 credit of Bioengineering Seminar (BMEP 501). A list of approved courses can be found in 167 Olin Hall.

## MINOR: BIOMEDICAL ENGINEERING

Offered by the Department of Biomedical Engineering (BME)

Contact: 270 Olin Hall, 255–1003, www.bme.cornell.edu/

BME is responsible for a new minor program in biomedical engineering. Students graduating in the Class of 2006 and later must complete the minor as specified by BME. Students graduating in 2005 may elect to complete the requirements in the Biomedical Engineering Minor offered by Theoretical and Applied Mechanics (T&AM).

All engineering majors are eligible to participate in this minor. Students may participate in only one of the Bioengineering option, the Biological Engineering minor and the Biomedical Engineering minor.

Educational Objectives: Biomedical engineering is the application of engineering principles and methods to a wide array of problems associated with human health. The field includes the design of biocompatible materials, prostheses, surgical implants, artificial organs, controlled drug-delivery systems, and wound closure devices. Diagnosing diseases and determining their biological origins depend upon increasingly sophisticated instrumentation and the use of mathematical models. This minor allows students in the College of Engineering to gain exposure to the breadth and depth of biomedical engineering offerings at Cornell, to prepare for advanced studies in biomedical engineering, and to obtain recognition for their interest and capability in area.

Interested students are asked to register with the Biomedical Engineering Office (270 Olin). A BME faculty adviser will be assigned and will approve the student's BME minor plan.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

Required course: BMEP 501, Bioengineering Seminar (1 credit)

At least six courses (≥ 18 credits) from the five groups listed below, with at least four of the groups represented and four of which must be from categories 3, 4, and 5 (two courses should be in categories 1 and/or 2 with no more than one course from category 1). At least four of the six courses must be from outside the student's major department.

1. Introductory biology (≤ 4 credits and one course toward the BMEP minor)

   BIO G 110 and ENGRI 101 Biological Principles and Introduction to Biomedical Engineering Analysis

   BIO G 101, 102, 103, and 104 Biological Sciences

   BIO G 105 and 106 Introductory Biology

BIO G 107 and 108 General Biology

A "5" on AP Biology Test

2. Advanced biology

BIOBM 330 Principles of Biochemistry, Individualized Instruction

BIOBM 333 Principles of Biochemistry, Proteins, Metabolism, and Molecular Biology

BIOBM 331 and 332 Principles of Biochemistry, Proteins and Metabolism and Principles of Biochemistry, Molecular Biology

BIOAP 311 Introductory Animal Physiology Lectures

BIOGD 281 Genetics

BIONB 222 Introduction to Neurobiology

BIOMI 290 General Microbiology Lectures

BIOGD 389 Embryology

3. Molecular and cellular biomedical engineering

BMEP 301 (CHEME 401)* Molecular Principles of Biomedical Engineering

BMEP 302 (CHEME 402)* Cellular Principles of Biomedical Engineering

A&EP 252 The Physics of Life

BEE 360 Molecular and Cellular Bioengineering

4. BMEP analysis of physiological systems

BMEP 401 (M&AE 466)* Biomedical Engineering of Metabolic and Structural Systems

BMEP 402* Information Exchange in BMEP Systems

M&AE 464 Orthopaedic Tissue Mechanics

M&AE 463 Neuromuscular Biomechanics

BEE 454 Physiological Engineering

CHEME 481 Biomedical Engineering

BIONB 330 Introduction to Computational Neuroscience

BIONB 491 Principles of Neurophysiology

5. Biomedical engineering applications

A&EP 470 Biophysical Methods

BEE 450 Bioinstrumentation

BEE 453 Computer-Aided Engineering: Applications to Biomedical Processes

BEE 459 Biosensors and Bioanalytical Techniques

COM S 321 Numerical Methods in Computational Molecular Biology

ECE 402 CDE in Biomedical System Design

ECE 336 Nanofabrication

ECE 578 Computer Analysis of Biomedical Images

BIONB 440 Electronics in Neurobiology

BIONB 441 Computers in Neurobiology

BEE 365 Properties of Biological Materials

MS&E 461 or TXA 439 Biological Materials and Their Applications or Biomedical Materials and Devices for Human Body Repair

M&AE 565 Biomechanical Systems—Analysis and Design

*The M.Eng. degree in BME recommends that students complete the sequence BMEP 301, 302, 401, 402. A knowledge of molecular and cellular biomedical engineering and of biomedical engineering analysis of physiological systems is expected for students entering the M.Eng. in BME degree program.

## MINOR: BIOMEDICAL ENGINEERING

Offered by the Department of Theoretical and Applied Mechanics

Contact: James Jenkins, 221 Kimball Hall, 255–7185, jtj2@cornell.edu, www.tam.cornell.edu/Undergrad.html

All engineering undergraduates are eligible to participate in this minor unless they also are pursuing the Bioengineering Option. (Students may participate in either the Bioengineering Option or the Biomedical Engineering minor, but not both.)

Educational Objectives: Biomedical engineering is the application of engineering principles and methods to a wide array of problems associated with human health. The field includes the design of biocompatible materials, prostheses, surgical implants, artificial organs, controlled drug-delivery systems, and wound closure devices. Diagnosing diseases and determining their biological origins depend upon increasingly sophisticated instrumentation and the use of mathematical models. The purpose of this minor is to allow students in the College of Engineering to gain exposure to the breadth and depth of biomedical engineering offerings at Cornell, to prepare for advanced studies in biomedical engineering, and to obtain recognition for their interest and capability in this rapidly growing area.

**Academic Standards:** At least C- in each course in the minor.

**Requirements**

All students must take ENGRG 501, Bioengineering Seminar (1 credit).

In addition, students must take at least six (6) courses (with a minimum total of 18 credits) from the five groups listed, with at least one course from each group. Four of the six courses must be outside the student's major.

I. Biomaterials and Biomechanics

BEE 365 (3) Properties of Biological Materials

MS&E 265 (3) or TXA 439 (2) Biological Materials and Their Synthetic Replacements

M&AE 463 (3) Neuromuscular Biomechanics

M&AE 464 (3) Orthopaedic Tissue Mechanics

M&AE 565 (3) Biomechanical Systems—Analysis and Design

M&AE 664 (3) Mechanics of Bone

ENGRG 605.3 (1) Biomaterials

ENGRG 606.1 (1) Artificial Organs and Tissue Engineering

ENGRG 606.3 (1) Biomechanics of Musculoskeletal Systems

BMEP 665/MSE 665/MAE 665 (3) Principles of Tissue Engineering

II. Biomedical Systems

BEE 453 (3) Computer-Aided Engineering: Application to Biomedical and Food Processes

CHEME 481 (3) Biomedical Engineering

BEE 454 (3) Physiological Engineering

ENGRG 605.1 (1) Cellular Dynamics and Cancer

ENGRG 605.2 (1) Physiological Systems

MAE 466/BMEP 401 (3) Biomedical Engineering Analysis of Metabolic and Structural Systems

AEP 252 (3) The Physics of Life

COM S 426 (3) Introduction to Computation Biology

III. Instrumentation

BEE 418 (3) Introduction to Biotechnology

ECE 432 (3) MicroElectro Mechanical Systems (MEMS)

ECE 511 (3) Bioelectric Signal Analysis and Processing

ENGRG 606.2 (1) Biomedical Instrumentation and Diagnosis

BEE 459/659 (3) Biosensors and Bioanalytical Techniques

BEE 450 (4) Bioinstrumentation

IV. Molecular and Cell Biology

BIOGD 281 (5) Genetics

BIOGD282 (2-3) Human Genetics

BIOMI 290 (3) Microbiology

BIOAP 316 (4) Cellular Physiology

BIOBM 330–333 (2–4) Principles of Biochemistry

BIOBM 432 (3) Survey of Cell Biology

V. Physiology

BIOAP 212 (3) Human Physiology

BIOAP 311 (3) Introductory Animal Physiology

BIOAP 313 (4) Histology: The Biology of the Tissues

BIOGD 389 (3) Embryology

BIONB 222 (3–4) Neurobiology and Behavior II: Introduction to Neurobiology

AN SC 427 (3) Fundamentals of Endocrinology

## MINOR: CIVIL INFRASTRUCTURE

Offered by the School of Civil and Environmental Engineering

Contact: 221 Hollister Hall, 255–3412, www.cee.cornell.edu

Students affiliated with all majors except Civil Engineering and Environmental Engineering are eligible to participate in this minor.

The minor in civil infrastructure is intended to introduce engineering undergraduates to the engineering methodologies of mechanics, materials, analysis, design, and construction and to show how these are used in solving problems in the development, maintenance, and operation of the built environment that is vital for any modern economy.

**Academic standards:** At least C in each course in the minor

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. Required course: ENGRD 202 Mechanics of Solids

II. Additional courses: choose any 5 (groupings are for information only)*

**Geotechnical engineering**

CEE 341 Introduction to Geotechnical Engineering and Analysis

CEE 440 Foundation Engineering

CEE 441 Retaining Structures and Slopes

CEE 444 Environmental Site and Remediation Engineering

**Structural engineering**

CEE 371 Structural Modeling and Behavior

CEE 372 Structural Mechanics and Analysis

CEE 471 Fundamentals of Structural Mechanics

CEE 472 Finite Element Analysis of Solids and Structures

CEE 473 Design of Concrete Structures

CEE 474 Design of Metal Structures

CEE 481 LRFD-Based Engineering of Wood Structures

**Other related courses**

CEE 595 Construction Planning and Operations

*Other CEE courses may be approved by petition in advance

## MINOR: COMPUTER SCIENCE

Offered by the Department of Computer Science

Contact: Upson 303, 255–9220, www.cs.cornell.edu

Students affiliated with all majors except Computer Science and Information Science, Systems, and Technology are eligible to participate in this minor. This minor is for students who anticipate that computer science will play a prominent role in their academic and professional career.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits) chosen as follows:

I. Required courses

COM S/ENGRD 211 Computers and Programming

One of the following:

COM S 321 Numerical Methods in Computational Biology,

COM S/ENGRD 322 Introduction to Scientific Computing,

COM S 421 Numerical Analysis,

COM S 428 Introduction to Computational Biophysics,

COM S/ECE 314 Computer Organization

II. Additional courses

Three COM S courses numbered 280 or higher (excluding seminars and COM S 490).

Computing courses offered by other departments cannot be applied toward the Computer Science minor, with the exception of ECE 314. All qualifying courses should be taken at Cornell for a letter grade. No substitutions allowed.

## MINOR: ELECTRICAL AND COMPUTER ENGINEERING

Offered by the School of Electrical and Computer Engineering

Contact: 223 Phillips Hall, 255–4309, www.ece.cornell.edu

Students affiliated with all majors except Electrical and Computer Engineering are eligible to participate in this minor, but MSE students must receive prior written approval from both MS&E and ECE, via petition.

This minor offers the opportunity to study analog and digital circuits, signals and systems, and electromagnetics and to concentrate at higher levels in one of several different areas such as circuit design, electronic devices, communications, computer engineering, networks, and space engineering.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.3 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. Two of the following:

ECE/ENGRD 210 Introduction to Circuits for Electrical and Computer Engineers (4 credits)

ECE 220 Signals and Information

ENGRD 230 Introduction to Digital Logic Design

II. Two of the following:

ECE 303 Electromagnetic Fields and Waves

ECE/CS 314 Computer Organization

ECE 315 Introduction to Microelectronics

ECE 320 Networks and Systems

III. One other ECE course at the 300 level or above (3-credit minimum)

IV. One other ECE course at the 400 level or above (3-credit minimum)

## MINOR: ENGINEERING MANAGEMENT

Offered by the School of Civil and Environmental Engineering

Contact: 221 Hollister Hall, 255–3412, www.cee.cornell.edu

Students affiliated with all majors except Civil Engineering and Environmental Engineering are eligible to participate in this minor.

This minor focuses on giving engineering students a basic understanding of engineering economics, accounting, statistics, project management methods, and analysis tools necessary to manage technical operations and projects effectively. The minor provides an important set of collateral skills for students in any engineering discipline.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. Required courses (3):

CEE 323 Engineering Economics and Management

OR&IE 350 Financial and Managerial Accounting

CEE 304 Uncertainty Analysis in Engineering

or ENGRD 270 Basic Engineering Probability and Statistics

or ECE 310 Introduction to Probability and Random Signals

II. Additional courses—choose any three*

CEE 490 Management Practice in Project Engineering

CEE 492 Engineers for a Sustainable World: Engineering in International Development

CEE 406 Civil Infrastructure Systems

CEE 593 Engineering Management Methods: Data, Information, and Modeling

CEE 594 Economic Methods for Engineering and Management

CEE 595 Construction Planning and Operations

CEE 596 Management Issues in Forensic Engineering

CEE 597 Risk Analysis and Management

CEE 598 Introduction to Decision Analysis

NBA 507 Entrepreneurship for Scientists and Engineers

or M&AE/ENGRG 461/OR&IE 452 Entrepreneurship for Engineers

or BEE 489 Engineering Entrepreneurship, Management and Ethics

*Other courses approved by petition in advance.

T&AM 310 may not be substituted for CEE 304.

## MINOR: ENGINEERING STATISTICS

Offered by the School of Operations Research and Industrial Engineering

Contact: 202 Rhodes Hall, 255–5088, www.orie.cornell.edu

Students affiliated with all majors except Operations Research and Engineering are eligible to participate in this minor.

The goal of the minor is to provide the student with a firm understanding of statistical principles and engineering applications and the ability to apply this knowledge in real-world situations.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. Required courses:

ENGRD 270 Basic Engineering Probability and Statistics

OR&IE 360 or ECE 310 Basic Engineering Probability and Statistics II or Introduction to Probability and Random Signals

II. Four of these (≥ 11 credits)*:

OR&IE 361 or ECE 411 Introductory Engineering Stochastic Processes I or Random Signals in Communications/Signal Processing

OR&IE 476 Applied Linear Statistical Models

OR&IE 576 Regression

OR&IE 563 Applied Time Series Analysis

OR&IE 575 Experimental Design

OR&IE 577 Quality Control

OR&IE 580 Simulation Modeling and Analysis

MATH 472 or BTRY 409 Basic Probability or Theory of Statistics

BTRY 602 Statistical Methods II

BTRY 603 or ILRST 411 Statistical Methods III or Statistical Analysis of Qualitative Data

ILRST 310 Statistical Sampling

ILRST 314 Graphical Methods for Data Analysis

ILRST 410 Techniques of Multivariate Analysis

*Other course options approved by petition in advance. Some of these courses require others as prerequisites. All these courses are cross-listed under the Department of Statistical Science.

## MINOR: ENVIRONMENTAL ENGINEERING

Offered jointly by the Department of Biological and Environmental Engineering and the School of Civil and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255–2173, www.bee.cornell.edu, or 221 Hollister Hall, 255–3412, www.cee.cornell.edu

Students affiliated with all majors except Biological Engineering, Civil Engineering, and Environmental Engineering are eligible to participate in this minor.

A fundamental challenge for the engineering profession is development of a sustainable society and environmentally responsible industry and agriculture reflecting an integration of economic and environmental objectives. We are called upon to be trustees and managers of our nation's resources, the air in our cities, and water in our aquifers, streams, estuaries, and coastal areas. This minor encourages engineering students to learn about the scientific, engineering, and economic foundations of environmental engineering so that they are better able to address environmental management issues.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen from the following groups, with at least one course from each group.

**Group A. Environmental engineering processes:**

BEE 251 Engineering for a Sustainable Society

CEE 351 Environmental Quality Engineering

CEE 451 Microbiology for Environmental Engineering

CEE 452 Water Supply Engineering

CEE 453 Laboratory Research in Environmental Engineering

CEE 454 Sustainable Small-Scale Water Supplies

BEE 476 Solid Waste Engineering

BEE 478 Ecological Engineering

CEE 444 Environmental Site and Remediation Engineering

BEE 651 Bioremediation

CEE 653 Water Chemistry for Environmental Engineering

CEE 656 Physical/Chemical Process

CEE 657 Biological Processes

CEE 658 Microbial Biodegradation and Biocatalysis Lab

**Group B. Environmental systems**

ENGRI 113/CEE 113* Solving Environmental Problems for Urban Regions (*may count only if taken before the junior year)

BEE 475 Environmental Systems Analysis

CEE 597 Risk Analysis and Management

CEE 623 Environmental Quality Systems Engineering

BEE 678 Nonpoint Source Models

**Group C. Hydraulics, hydrology, and environmental fluid mechanics**

CEE 331 Fluid Mechanics (CHEME 323 or M&AE 323 may be substituted for CEE 331)

CEE 332 Hydraulic Engineering

BEE 371 Hydrology and the Environment

CEE 431/BEE 471 Introduction to Groundwater Hydrology

CEE 432 Hydrology

CEE 436 Case Studies in Environmental Fluid Mechanics

CEE 437 Experimental Methods in Fluid Dynamics

BEE 473 Watershed Engineering

BEE 474 Drainage and Irrigation Systems

CEE 631 Computational Simulation of Transport in the Environment

CEE 633 Flow in Porous Media and Groundwater

CEE 655 Transport, Mixing, and Transformation in the Environment

BEE 671 Analysis of the Flow of Water and Chemicals in Soils

BEE 672 Drainage

## MINOR: GEOLOGICAL SCIENCES

Offered by the Department of Earth and Atmospheric Sciences

Contact: 2124 Snee Hall, 255–5466, www.eas.cornell.edu

Students affiliated with all majors except Geological Sciences are eligible to participate.

Some of the major problems facing mankind in this century involve earth science, especially the generation of new energy sources for a growing world population, and engineers will be challenged to solve these problems. This minor will prepare engineering students to understand the natural operating systems of Earth and the tools and techniques used by Earth scientists to understand and monitor these solid and fluid systems.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. At least one of these courses:

ENGRD 201 Introduction to the Physics and Chemistry of the Earth

EAS 210 Introduction to Field Methods in Geological Sciences

II. At least two of these courses:

EAS 302 Evolution of the Earth System

EAS 321 Introduction to Biogeochemistry

EAS 326 Structural Geology

EAS 355 Mineralogy

EAS 356 Petrology and Geochemistry

EAS 375 Sedimentology and Stratigraphy

EAS 388 Geophysics and Geotectonics

III. Additional EAS courses at the 300 level or higher. These may include, e.g., additional courses from the above lists, undergraduate research courses, and outdoor field courses.

## MINOR: INDUSTRIAL SYSTEMS AND INFORMATION TECHNOLOGY

Offered by the School of Operations and Industrial Engineering

Contact: 202 Rhodes Hall, 255–5088, www.orie.cornell.edu

Students affiliated with all majors except Operations Research and Engineering are eligible to participate in this minor.

The aim of this minor is to provide an in-depth education in the issues involved in the design and analysis of industrial systems, and the tools from information technology that have become an integral part of the manufacturing process. Students will become familiar with the problems, perspectives, and methods of modern industrial engineering and be prepared to work with industrial engineers in designing and managing manufacturing and service operations. That is, rather than providing a comprehensive view of the range of methodological foundations of operations research, this minor is designed to give the student a focused education in the application area most closely associated with these techniques.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. At least three of the following:

ENGRD 270 Basic Engineering Probability and Statistics

OR&IE 310 Industrial Systems Analysis

OR&IE 320 Optimization I

OR&IE 480 Information Technology

II. The remaining courses chosen from:

OR&IE 350 Financial and Managerial Accounting

OR&IE 416 Design of Manufacturing Systems

OR&IE 451 Economic Analysis of Engineering Systems

OR&IE 525 Production Planning and Scheduling Theory and Practice

OR&IE 577 Quality Control

OR&IE 580 Simulation Modeling and Analysis

## MINOR: INFORMATION SCIENCE

Offered by the Department of Computer Science

Contact: Undergraduate Programs Office, Upson 303, 255–9837, www.infosci.cornell.edu

Students affiliated with any major except Information Science, Systems, and Technology are eligible to participate in this minor.

The interdisciplinary field of information science covers all aspects of digital information. The program has three main areas: Information Systems, Human-centered Systems, and Social Systems. Information Systems studies the computer science problems of representing, storing, manipulating, and using digital information. Human-centered Systems studies the relationship between humans and information, drawing from human-computer interaction and cognitive science. Social Systems examines information in its economic, legal, political, cultural, and social contexts.

The minor has been designed to ensure that students have substantial grounding in all three areas in addition to having a working knowledge of basic probability and statistics necessary for analyzing real-world data.

**Academic standards:** At least C in all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits) chosen as follows:

- Statistics: one course
- Information systems (primarily computer science): two courses
- Human-centered systems (human computer interaction and cognitive science): one course
- Social systems (social, economic, political, cultural, and legal issues): one course
- Elective: one additional course from either human-centered systems or social systems

**Statistics**

An introductory course that provides a working knowledge of basic probability and statistics and their application to analyzing real-world data.

ENGRD 270 Basic Engineering Probability and Statistics

CEE 304 Uncertainty Analysis in Engineering

ECE 310 Introduction to Probability and Random Signals

**Information Systems**

COM S 211 Computers and Programming*

INFO 230 Intermediate Design and Programming for the Web*

INFO 330 Applied Database Systems

LING 424 Computational Linguistics

INFO 430 Information Retrieval

INFO 431 Web Information Systems

COM S 432 Introduction to Database Systems

COM S 465 Computer Graphics I

COM S 472 Foundations of Artificial Intelligence

LING 474 Introduction to Natural Language Processing

OR&IE 474 Statistical Data Mining

COM S 478 Machine Learning

OR&IE 480 Information Technology

COM S 501 Software Engineering

ECE 562 Fundamental Information Theory

COM S 578 Empirical Methods in Machine Learning and Data Mining

*Computer Science majors cannot use INFO 230. COM S 211 cannot be used by majors for which it is a required course, e.g., Computer Science and Operations Research Engineering.

**Human-centered Systems**

COGST 101 Introduction to Cognitive Science

PSYCH 205 Perception

INFO 214 Cognitive Psychology

INFO 245 Psychology of Social Computing

PSYCH 280 Introduction to Social Psychology

PSYCH 342 Human Perception: Applications to Computer Graphics, Art, and Visual Display

INFO 345 Human-Computer Interaction Design

PSYCH 347 Psychology of Visual Communications

PSYCH 380 Social Cognition

PSYCH 413 Information Processing: Conscious and Unconscious

PSYCH 416 Modeling Perception and Cognition

INFO 440 Advanced Human-Centered Systems

INFO 450 Language and Technology

DEA 470 Applied Ergonomics Methods

**Social Systems**

S&TS 250 Technology in Society

INFO 292 Inventing an Information Society

ECON 301 Microeconomics*

SOC 304 Social Networks and Social Processes

ECON 313 Intermediate Microeconomic Theory*

AEM 322 Technology, Information, and Business Strategy

INFO 349 Media Technologies

INFO 355 Computers: From Babbage to Gates

ECON 368 Game Theory*

INFO 387 The Automatic Lifestyle: Consumer Culture and Technology

LAW 410 Limits on and Protection of Creative Expression—Copyright Law and Its Close Neighbors

S&TS 411 Knowledge, Technology, and Property

ECON 419 Economic Decisions Under Uncertainty

COMM 428 Communication Law

OR&IE 435 Introduction to Game Theory*

STS 438 Minds, Machines, and Intelligence

INFO 447 Social and Economic Data

ECON 476/477 Decision Theory I and II

CIS 515 Culture, Law, and Politics of the Internet

*Only one of ECON 301 and ECON 313. Only one of OR&IE 435 and ECON 368.

## MINOR: MATERIALS SCIENCE AND ENGINEERING

Offered by the Department of Materials Science and Engineering

Contact: 214 Bard Hall, 255–4135, www.mse.cornell.edu

Students affiliated with all majors except Materials Science and Engineering are eligible to participate in this minor.

Material properties are the foundation of many engineering disciplines including mechanical, civil, chemical, and electrical engineering. This minor provides engineers in related areas with a fundamental understanding of mechanisms that determine the ultimate performance, properties, and processing characteristics of modern materials.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. ENGRD 261 Mechanical Properties of Materials, From Nanodevices to Superstructures, or ENGRD 262, Electronic Materials for the Information Age
2. Two of:

   MS&E 204 Materials Chemistry

   MS&E 206 Atomic and Molecular Structure of Matter

   MS&E 302 Mechanical Properties of Materials, Processing, and Design

   MS&E 303 Thermodynamics of Condensed Systems

   MS&E 304 Kinetics, Diffusion, and Phase Transformations

   MS&E 305 Electronic, Magnetic, and Dielectric Properties of Materials
3. Three electives chosen from:

   Any MS&E course at the 300 level or above.

Selected courses in materials properties and processing (at the 300 level or above) from A&EP, CHEME, CEE, ECE, M&AE, PHYS, and CHEM, as approved by the MS&E undergraduate major coordinator.

## MINOR: MECHANICAL ENGINEERING

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 108 Upson Hall, 255–3573, www.mae.cornell.edu

Students affiliated with all majors except Mechanical Engineering are eligible to participate in this minor. Students intending to earn a minor in Mechanical Engineering should seek advice and pre-approval of their minor academic program from the associate director of undergraduate affairs in Mechanical Engineering before taking courses toward the minor.

**Academic standards:** At least C- in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits) from among the following: M&AE courses at the 200 level or above; ENGRD 202, Mechanics of Solids; ENGRD 203, Dynamics.

Rules for selecting courses:

1. The selection of courses must satisfy the following three requirements.
   a) At least two courses must be numbered above 300.
   b) At least one course must be either 1) numbered above 500 or 2) numbered above 326 and have as a prerequisite ENGRD 202, ENGRD 203, or an M&AE course.
   c) Each course must be worth at least 3 credits.
2. All courses used to satisfy the M&AE minor must be M&AE courses, ENGRD 202, or ENGRD 203. No substitutions will be accepted from other departments at Cornell or elsewhere. Transfer credit cannot be used to satisfy the M&AE minor.

## MINOR: OPERATIONS RESEARCH AND MANAGEMENT SCIENCE

Offered by the School of Operations Research and Industrial Engineering

Contact: 202 Rhodes Hall, 255–5088, www.orie.cornell.edu

Students affiliated with all majors except Operations Research and Engineering are eligible to participate in this minor.

Operations research and management science aims to provide rational bases for decision making by seeking to understand and model complex situations and to use this understanding to predict system behavior and improve system performance. This minor gives the student the opportunity to obtain a wide exposure to the core methodological tools of the area, including mathematical programming, stochastic and statistical models, and simulation. The intent of this minor is to give a broad knowledge of these fundamentals, rather than to train the student in a particular application domain. This way, students can adjust their advanced courses and pursue either methodological or application-oriented areas of greatest interest and relevance to the overall educational goals of their program.

**Academic standards:** At least C- in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

I. At least three of these courses:

   ENGRD 270 Basic Engineering Probability and Statistics

   OR&IE 320 Optimization I

   OR&IE 321 Optimization II

   OR&IE 360 Engineering Probability and Statistics II

   OR&IE 361 Introduction Engineering Stochastic Processes I

   OR&IE 580 Simulation Modeling and Analysis

II. Any OR&IE courses at the 300 level or higher (including those in I).

## MASTER OF ENGINEERING DEGREES

Office of Research, Graduate Studies, and Professional Education (ORGSPE), 222 Carpenter Hall, www.engineering.cornell.edu/grad

The following one-year (30-credit) professional master of engineering (M.Eng.) degrees are offered (giving also the administering unit)

**M.Eng. (Aerospace):** Mechanical and Aerospace Engineering

**M.Eng. (Agricultural and Biological):** Biological and Environmental Engineering

**M.Eng. (Biomedical):** Biomedical Engineering

**M.Eng. (Chemical):** Chemical and Biomolecular Engineering

**M.Eng. (Civil):** Civil and Environmental Engineering

**M.Eng. (Computer Science):** Computer Science

**M.Eng. (Electrical):** Electrical and Computer Engineering

**M.Eng. (Engineering Mechanics):** Theoretical and Applied Mechanics

**M.Eng. (Engineering Physics):** Applied and Engineering Physics

**M.Eng. (Geological Sciences):** Earth and Atmospheric Sciences

**M.Eng. (Materials):** Materials Science and Engineering

**M.Eng. (Mechanical):** Mechanical and Aerospace Engineering

**M.Eng. (Nuclear):** Graduate Field of Nuclear Science and Engineering

**M.Eng. (OR&IE):** Operations Research and Industrial Engineering

**M.Eng. (Systems):** Systems Engineering

These degrees are discussed in *Courses of Study* (below) because the curricula are integrated with the undergraduate majors.

Many Cornell baccalaureate engineering graduates spend a fifth year at Cornell, earning an M.Eng. degree, although the program is also open to qualified graduates of other schools.

Requirements for admission vary by program. In general, the standard M.Eng. application requirements include:

- Statement of purpose
- Complete transcripts from each college or university attended
- At least two letters of recommendation
- Graduate Record Examination (GRE) scores—may not be required by all M.Eng. programs

Many M.Eng. programs waive the GRE requirement and one of the letters of recommendation for students with Cornell Engineering B.S. degrees. Check with the appropriate office for specific program requirements. A list of links and general admission information is posted on www.engr.cornell.edu/grad.

Superior Cornell students who will have between 1 and 8 credits remaining in their last undergraduate semester may petition for early admission to the M.Eng. program. They spend the last semester in both programming, finishing up their B.S. degree and also doing their first semester of the M.Eng. program.

### Master of Engineering Options

The following M.Eng. options are offered:

- Bioengineering Option
- Financial Engineering Option
- Manufacturing Option
- Engineering Management Option
- Systems Engineering Option

### Cooperative Program with the Johnson Graduate School of Management

Undergraduates may be interested in a cooperative program at Cornell that leads to both master of engineering and master of business administration (M.B.A.) degrees. With appropriate curriculum planning, such a combined B.S./M.Eng./M.B.A. program can be completed in six years at Cornell, with time out for work experience. For undergraduates from other schools, it may be feasible to complete the M.Eng./M.B.A. program in two years, possibly with an intervening summer or time out for work experience if they do not already have it on coming to Cornell. This accelerated program often incorporates the Twelve-Month M.B.A. Program of the Johnson Graduate School of Management (JGSM).

Since 95 percent of the students in the JGSM have work experience, there will typically be a gap for work experience between the M.Eng. and M.B.A. portions of the program for students who do not already have it when beginning the M.Eng. portion.

For further details, see Engineering Advising (167 Olin Hall), the M.Eng. office (222 Carpenter), the JGSM office in Sage Hall, or the office of your intended undergraduate major.

### Lester Knight Scholarship Program

The Lester Knight Scholarship Program is designed to assist and encourage Cornell Engineering students and alumni interested in combining their engineering education with a business degree. The program offers three options or categories of financial support:

- Alumni Knight Scholarship Option
- Undergraduate Knight Scholarship Option
- Six-Year Knight Scholarship Option

Each program has different qualifications and is open to Cornell engineering students and alumni at different stages of their educational or professional career. Participation in the program requires admission by each respective academic program (M.Eng, M.B.A.) as well as an application to participate in the Knight Scholarship Program.

Contact ORGSPE or refer to the Knight Scholarship web site (www.engr.cornell.edu/grad/knight) for program specifics.

## MASTER OF ENGINEERING (AEROSPACE)

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 107 Upson Hall, 255–5250, www.mae.cornell.edu

The M.Eng. (Aerospace) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

The program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas. These include aerodynamics, acoustics and noise, turbulent flows, nonequilibrium flows, combustion, dynamics and control, and computational fluid dynamics.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. This program and any subsequent changes must also be approved by the chair of the M&AE Master of Engineering committee. An individual student's curriculum includes a 4- to 8-credit design course, a minimum of 12 credits in aerospace engineering or a closely related field, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

Design projects must have an aerospace engineering design focus and have the close supervision of a faculty member. The projects may arise from individual faculty and student interests or from collaboration with industry.

All courses must be of true graduate nature. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have the approval of the M&AE Master of Engineering chair.

The technical electives may be courses of appropriate level in math, physics, chemistry, or engineering; a maximum of 3 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. Students are expected to use technical electives to develop proficiency in math beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering math or statistics are particularly recommended.

Check with the M&AE graduate field office (107 Upson Hall) for additional degree requirements.

Students enrolled in the M.Eng. (Aerospace) degree program may take courses that also satisfy the requirements of the bioengineering, engineering management, or systems engineering options.

## MASTER OF ENGINEERING (AGRICULTURAL AND BIOLOGICAL)

Offered by the Department of Biological and Environmental Engineering

Contact: 207 Riley Robb Hall, 255–2173, www.bee.cornell.edu

This degree is intended primarily for students who plan to enter engineering practice. The program is planned as an extension of an undergraduate major in biological and environmental engineering but can accommodate graduates of other engineering disciplines. The required 30 credits of courses are intended to strengthen the students' fundamental knowledge of engineering and develop their design skills. Of the 30 credits, 3 to 9 are earned for an engineering design project that culminates in a written and oral report.

Students may concentrate in any of a variety of areas: biological engineering, energy, environmental engineering, environmental management, food processing engineering, international agriculture, local roads, machine systems, soil and water engineering, and structures and environment. Elective courses are chosen from among engineering subject areas relevant to the student's interests and design project. Courses in technical communication, math, biology, and the physical sciences may also be taken as part of a coherent program. Students can qualify for the Dean's Certificate in energy, manufacturing, or bioengineering by choosing their design project and a number of electives from the designated topic areas.

## MASTER OF ENGINEERING (BIOMEDICAL)

Offered by the Department of Biomedical Engineering

Contact: 270 Olin Hall, 255-1003, www.bme.cornell.edu

Our mechanistic understanding of biology has increased rapidly over the past 20 years, and many expect biology to drive engineering and technology in the next 50 years in much the same way that physics drove them in the twentieth century. As biology has become more mechanistic, the opportunities to apply engineering approaches have increased enormously. Simultaneously, humanitarian needs and economic opportunities for the application of engineering to improve health care have increased significantly. Engineers who understand biology and can apply their knowledge and skills to improve human health are increasingly in demand. A professional degree in BME will prepare students to fill this increasing critical need.

The breadth and depth of knowledge needed in biomedical engineering makes a four-year B.S. degree program impractical. By combining the M.Eng. in BME with a strong B.S. program, a student can obtain the knowledge and skills necessary to be an effective professional biomedical engineer.

Students will acquire an in-depth knowledge of an essential area of biomedical engineering as well as a broad perspective of the biomedical engineering discipline that complements their undergraduate education in engineering or science. Graduates will be equipped to design biomedical devices and develop therapeutic strategies within the bounds of health care economics, the needs of patients and physicians, the regulatory environment for medical devices and pharmaceuticals, and stringent ethical standards.

Students will acquire depth by extending undergraduate concentrations, by selecting one of three area for concentrated study, and by completing a design project in their area of concentration. The areas are biomedical mechanics and materials; bioinstrumentation/diagnostics; and drug delivery and cellular/tissue engineering. Design projects will be carried out in teams to take advantage of the diversity of student backgrounds and, when possible, projects will be done in collaboration with industrial or clinical partners.

Students from a wide variety of backgrounds in engineering and science are encouraged to apply. They are expected to have completed two semesters of calculus-based physics, at least three semesters of math, starting with calculus, and introductory computer science.

A knowledge of molecular- and cellular-base biomedical engineering and engineering analysis of physiological systems at the level of BMEP 301, 302, 401, and 402 is highly recommended. This knowledge can be demonstrated through appropriate undergraduate course work (at least C in each class) or by passing a diagnostic exam. Students lacking the appropriate background will need to complete additional courses (beyond the normal 30 credits) to demonstrate appropriate knowledge in these two subject areas.

## MASTER OF ENGINEERING (CHEMICAL)

Offered by the School of Chemical and Biomolecular Engineering

Contact: 120 Olin Hall, 255–6331, www.cheme.cornell.edu

This degree is awarded at the end of one year of graduate study with successful completion of 30 credits of required and elective courses in technical fields including engineering, math, chemistry, physics, and business administration. Courses emphasize design and optimization based on the economic factors that affect design alternatives for processes, equipment, and plants. General admission and degree requirements are described at the beginning of the section "Master of Engineering Degrees."

Specific requirements include

1. Twelve credits in CHEME courses distributed among chemical and biomolecular engineering fundamentals (CHEME 711, 731, and 751) and chemical and biomolecular engineering applications (partial list: CHEME 480, 481, 484, 520, 543, 572, 631, 640, and 661).
2. A minimum of 3 credits of an individual or group project, CHEME 565.
3. Knowledge of business practices and techniques for pollution abatement and control. This knowledge may have already been acquired by students as undergraduates. If not, then CHEME courses (such as CHEME 572 and 661) or other courses covering these topics are required.

## MASTER OF ENGINEERING (CIVIL)

Offered by the School of Civil and Environmental Engineering

Contact: 219 Hollister Hall, 255–7560, www.cee.cornell.edu

The M.Eng. (Civil) degree program is designed to prepare students for professional practice. There are two concentrations in this program: civil and environmental engineering design and engineering management. Both require a broad-based background in an appropriate engineering field. Applicants holding an ABET-accredited (or equivalent) undergraduate degree in engineering normally satisfy this requirement. Admitted applicants without adequate preparation will require course work beyond the 30-credit minimum to fulfill the engineering preparation requirement. Both concentrations also require one course in professional (design) or managerial (management) practice and a two-course project sequence. The project entails synthesis, analysis, decision making, and application of engineering judgment. Normally it is undertaken in cooperation with an outside practitioner, with some concentration areas using an intensive, full-time session between semesters.

The general degree requirements and admissions information are described above in the section "Master of Engineering Degree Programs." A student's program of study is designed individually in consultation with an academic adviser and then submitted to the school's Professional Degree Committee for approval.

For the M.Eng. (Civil) program in civil and environmental engineering design areas, the requirements are:

1. Three courses, one in professional engineering practice (CEE 503) and a two-course design project (CEE 501 and 502).
2. Work in a major concentration area: four courses in either environmental engineering, environmental fluid mechanics/hydrology, geotechnical engineering, structural engineering, or environmental and water resource systsems engineering.
3. Support electives, two required.

Courses taken as support electives may consist of graduate or advanced courses in fields related to the major concentration area, either inside or outside of CEE.

For the M.Eng. (Civil) program in engineering management, the requirements are:

1. Five courses: Project Management (CEE 590), Engineering Management Methods (CEE 593 plus either 594, 597, or 598), and the Management Project (CEE 591 and 592).
2. Two managerial breadth courses.
3. Three disciplinary or functional electives.

The School of Civil and Environmental Engineering cooperates with the Johnson Graduate School of Management in a joint program leading to both Master of Engineering and Master of Business Administration degrees. See the beginning of the section "Master of Engineering Degrees."

## MASTER OF ENGINEERING (COMPUTER SCIENCE)

Offered by the Department of Computer Science

Contact: 4126 Upson Hall, 255–8593, www.cs.cornell.edu/grad/meng

The M.Eng. program in computer science can be started in either the fall or spring semester. This program is designed to develop expertise in system design and implementation in many areas of computer science, including computer networks, Internet architecture, fault-tolerant and secure systems, distributed and parallel computing, high-performance computer architecture, databases and data mining, multimedia systems, computer vision, computational tools for finance, computational biology (including genomics), software engineering, programming environments, and artificial intelligence.

A typical program includes several upper-division and graduate courses and a faculty-supervised project. The flexible requirements allow students to build up a program that closely matches their interests. In fact, slightly under half the courses may be taken outside the computer science department (many students choose to take several business administration courses). Project work, which may be done individually or in a small group, can often be associated with ongoing research in the Department of Computer Science in one of the areas listed above.

Cornell seniors may use the early admission option to effectively co-register for the M.Eng. program while completing the undergraduate degree. This option can be started in either the fall or spring semester. It applies to students who have 1 to 8 credits remaining to complete their undergraduate program. All remaining undergraduate degree requirements must be satisfied by the end of the first semester the student is enrolled in the M.Eng. "early admit" program.

Undergraduates majoring in computer science may be interested in a program that can lead, in the course of six years, to B.S., M.Eng. (Computer Science), and M.B.A. degrees. See the section "Master of Engineering Degrees."

## MASTER OF ENGINEERING (ELECTRICAL)

Offered by the School of Electrical and Computer Engineering

Contact: 223 Phillips Hall, 255–8414, www.ece.cornell.edu/students/meng.html

The M.Eng. (Electrical) degree program prepares students either for professional work in electrical and computer engineering and closely related areas or for further graduate study in a doctoral program. The M.Eng. degree differs from the master of science degree mainly in its emphasis on professional skills, engineering design, and analysis skills rather than basic research.

The program requires 30 credits of advanced technical course work beyond that expected in a typical undergraduate program, including at least four courses in electrical and computer engineering. The required electrical and computer engineering design project may account for 3 to 8 credits of the M.Eng. program. Occasionally, students take part in very extensive projects and may petition to increase the project component to 10 credits. Students with special career goals, such as engineering management, may apply to use up to 11 credits of approved courses that have significant technical content but are taught in disciplines other than engineering, math, or the physical sciences.

Although admission to the M.Eng. (Electrical) program is highly competitive, all well-qualified students are urged to apply. Further information is available at the web site listed above.

## MASTER OF ENGINEERING (ENGINEERING MECHANICS)

Offered by the Department of Theoretical and Applied Mechanics

Contact: 212 Kimball Hall, 255–5062, www.tam.cornell.edu/meng.html

This program emphasizes fundamentals in engineering science and applied mathematics. In this way the student is prepared to handle a wide variety of multidisciplinary problems. The program is designed for engineering students and students from the physical and mathematical sciences.

Twelve of the required 30 course credits involve analysis, computation, design, or laboratory experience. Of these 12 credits, at least 6 must be earned in Theoretical and Applied Mechanics (T&AM). Up to 10 credits will be awarded for an M. Eng. project. The balance of the required 30 credits can be obtained as electives from T&AM or from other departments in the engineering, physical or mathematical sciences. Thus, students have great flexibility in choosing a course of study tailored to their interests.

Projects may be chosen from the current interests of the faculty, including: nonlinear dynamics and chaos (with applications to problems in physics, engineering and biology), solid mechanics (fracture mechanics, nonlinear elasticity, shape-memory alloys, composite materials, ultrasonics, and acoustics), fluid mechanics (granular materials), space mechanics (evolution of the solar system, planetary rings).

The Department of Theoretical and Applied Mechanics has several laboratories equipped for the fabrication and mechanical testing of composite materials and structures. Extensive computing resources are available for numerical computations, design, or other numerical- or simulation-research activities related to composites. The Materials Science Center, the Center for Theory and Simulation in Science and Engineering, and the Computer-Aided Design Instructional Facility provide additional state-of-the-art laboratories and computer resources.

## MASTER OF ENGINEERING (ENGINEERING PHYSICS)

Offered by the School of Applied and Engineering Physics

Contact: 212 Clark Hall, 255–5198, www.aep.cornell.edu

The M.Eng. (Engineering Physics) degree may lead directly to employment in engineering design and development or may be a basis for further graduate work. Students have the opportunity to broaden and deepen their preparation in the general field of applied physics, or they may choose the more specific option of preparing for professional engineering work in a particular area such as laser and optical technology, nanostructure science and technology, device physics, materials characterization, or software engineering. Wide latitude is allowed in the choice of the required design project.

One example of a specific area of study is solid-state physics and chemistry as applied to nano-structure science and technology. Core courses in this specialty include the nano-characterization of materials (A&EP 661) and the microprocessing and microfabrication of materials (A&EP 662). The design project may focus on such areas as semiconductor materials, device physics, nanostructure technology, and optoelectronics. Another area of study may be applied optics, where core courses can be chosen from applied physics, electrical engineering, and physics.

Students plan their program in consultation with the program chair. The objective is to provide a combination of a good general background in physics and introductory study in a specific field of applied physics. Candidates may enter with an undergraduate preparation in physics, engineering physics, or engineering. Those who have majored in physics usually seek advanced work with an emphasis on engineering; those who have majored in an engineering discipline generally seek to strengthen their physics base. Candidates coming from industry usually want instruction in both areas. Students granted the degree will have demonstrated competence in an appropriate core of basic physics; if this has not been accomplished at the undergraduate level, subjects such as electricity and magnetism, or classical, quantum, and statistical mechanics should be included in the program.

The degree requires 30 credits of graduate-level courses or their equivalent, with at least C- in each course, and distributed as follows:

1) a design project in applied science or engineering with a written final report (6 to 12 credits)
2) an integrated program of graduate-level courses, as discussed below (17 to 23 credits)
3) a required special-topics seminar course (1 credit)

The design project, which is proposed by the student and approved by the program chair, is carried out on an individual basis under the guidance of a member of the university faculty. It may be experimental or theoretical in nature; if it is not experimental, a laboratory physics course is required.

The individual program of study consists of a compatible sequence of courses focused on a specific area of applied physics or engineering. Its purpose is to provide an appropriate combination of physics and physics-related courses (applied math, statistical mechanics, applied quantum mechanics) and engineering electives (such as courses in biophysics, chemical engineering, electrical engineering, materials science, computer science, mechanical engineering, or nuclear engineering). Additional science and engineering electives may be included. Some courses at the senior level are acceptable for credit toward the degree; other undergraduate courses may be required as prerequisites but are not credited toward the degree.

## MASTER OF ENGINEERING (GEOLOGICAL SCIENCES)

Offered by the Department of Earth and Atmospheric Sciences

Contact: 2124 Snee Hall, 255–5466, www.eas.cornell.edu

The M.Eng. (Geological Sciences) degree program is a one-year course of study that provides future professional geologists or engineers with the geological and engineering background they will need to analyze and solve engineering problems that involve geological variables and concepts. Individual programs are developed within two established options: geohydrology and environmental geophysics.

Incoming students are expected to have a strong background in mathematics, the physical sciences, and chemistry and have a strong interest and substantial background in the geological sciences. The 30-hour M.Eng. program is intended to extend and broaden this background to develop competence in four subject categories. Typical categories for the geohydrology option are porous media flow, geology, geochemistry, and numerical modeling. Typical categories for the environmental geophysics option are geophysics, geology, porous media fluid flow, and computer methods. The courses a student selects in a category will vary depending on the student's background. No courses may be required in some categories, and the categories can be adjusted to the student's interest and needs. Alternatives to numerical modeling in the geohydrology option could be economics or biochemistry, for example. To count toward the 30-credit degree requirement, courses must be at a graduate or advanced undergraduate level.

At least 10 of the 30 hours in the program must involve engineering design. Much of this requirement is normally met through a design project, which can account for over a third of the program (12 of 30 credits) and must constitute at least 3 credits. The design project must involve a significant geological component and lead to concrete conclusions or recommendations of an engineering nature. The project topic can be drawn from a student's nonacademic work experience but carried out or further developed with advice from a Cornell faculty member with expertise in the project area selected by the student. A design project in geohydrology would normally involve groundwater flow and mass transport. A design project in environmental geophysics might involve implementation of a field survey using seismological, geoelectrical, or ground-penetrating radar methods to map subsurface stratigraphic or structural features that control groundwater flow or contamination at a site. Projects are presented both in written form and orally in a design seminar at the end of the year.

## MASTER OF ENGINEERING (MATERIALS SCIENCE AND ENGINEERING)

Offered by the Department of Materials Science and Engineering

Contact: 214 Bard Hall, 255-9159, www.mse.cornell.edu

Students who have completed a four-year undergraduate program in engineering or the physical sciences can be considered for admission into the M.Eng. (Materials) program. This 30-credit program includes course work and a master's design project. The project, which requires individual effort and initiative, is carried out under the supervision of a faculty member. Twelve credits are devoted to the project, which is normally experimental in nature, although computational or theoretical projects are also possible.

Courses for the additional 18 credits are selected from the graduate-level classes in materials science and engineering and from other related engineering fields approved by the faculty. Typically half of the courses are from MS&E. One 3-credit technical elective must include advanced math (modeling, computer application, or computer modeling), beyond the MS&E undergraduate requirements.

## MASTER OF ENGINEERING (MECHANICAL)

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 107 Upson Hall, 255-5250, www.mae.cornell.edu

The M.Eng. (Mechanical) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

Candidates may concentrate on any of a variety of specialty areas, including biomechanical engineering, combustion, propulsion and power systems, fluid mechanics, heat transfer, materials and manufacturing engineering, and mechanical systems and design.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. This program and any subsequent changes must also be approved by the chair of the M&AE Master of Engineering committee. An individual student's curriculum includes a 4- to 8-credit design course, a minimum of 12 credits in mechanical engineering or a closely related field, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have a mechanical engineering design focus and have the close supervision of a faculty member.

All courses must be of true graduate nature. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have special approval of the M&AE Master of Engineering chair.

The technical electives may be courses of appropriate level in math, physics, chemistry, or engineering; a maximum of 3 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. Students are expected to use technical electives to develop proficiency in math beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering math or statistics are particularly recommended.

Check with the M&AE graduate field office (107 Upson Hall) for additional degree requirements.

Students enrolled in the Master of Engineering (Mechanical) degree program may take courses that also satisfy the requirements of the bioengineering, engineering management, or systems manufacturing programs leading to special dean's certificates in those areas.

## MASTER OF ENGINEERING (NUCLEAR)

Offered by the Nuclear Engineering Program

Contact: 312 Rhodes Hall, 255-1453, www.gradschool.cornell.edu/academics_research/fields/nucl-sci.html

The two-term curriculum leading to the M.Eng. (Nuclear) degree is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The course of study covers the basic principles of nuclear reactor systems with a major emphasis on reactor safety and radiation protection and control.

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate concentrations. The recommended background is 1) an accredited baccalaureate degree in engineering, physics, or applied science; 2) physics, including atomic and nuclear physics; 3) math, including advanced calculus; and 4) thermodynamics. Students should see that they fulfill these requirements before beginning the program. In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer. General admission and degree requirements are described in the college's introductory section.

The following courses, or equivalents, are included in the 30-credit program:

*Fall term*

NS&E 509, Nuclear Physics for Applications

Technical elective

*Spring term*

NS&E 545, Energy Seminar

Technical elective

Engineering design project

Mathematics or physics elective

Engineering electives should be in a subject area relevant to nuclear engineering, such as energy conversion, radiation protection and control, feedback control systems, magnetohydrodynamics, controlled thermonuclear fusion, and environmental engineering. The list below gives typical electives.

A&EP 606/ECE 581, Introduction to Plasma Physics (fall, 4 credits)

A&EP 607, Basic Plasma Physics (spring, 4 credits)

A&EP 661, Microcharacterization (fall, 3 credits)

ECE 457, Silicon Device Fundamentals (fall, 4 credits with lab)

M&AE 478/CHEME 372, Feedback Control Systems (fall, 4 credits)

MS&E 459, Physics of Modern Materials Analysis (spring, 3 credits)

MS&E 603, Analytical Techniques for Materials Science (spring, 4 credits)

NS&E 484/A&EP 484/ECE 484/M&AE 459, Introduction to Controlled Fusion: Principles and Technology (spring, 3 credits)

NS&E 521, Radiation Effects in Materials (fall, 1-3 credits)

## MASTER OF ENGINEERING (OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING)

Offered by the School of Operations Research and Industrial Engineering

Contact: 201 Rhodes Hall, 255-9128, www.orie.cornell.edu

This two-semester professional degree program stresses applications of operations research and industrial engineering. The centerpiece of the program is a team-based project on a significant real-world problem. The course work centers on additional study of analytical techniques, with particular emphasis on engineering applications, especially in the design or improvement of systems in manufacturing, information, finance, and nonprofit organizations.

General admission and degree requirements are described in the introductory "Degree Programs" section. The M.Eng. (OR&IE) program is intended for three groups of students: graduates of the undergraduate major in ORE who wish to expand their practical knowledge of the field: Cornell undergraduates in other math-based area who want to broaden their exposure to OR&IE; and qualified non-Cornellians with strong backgrounds from other programs in the United States and abroad.

Undergraduates majoring in Operations Research and Engineering may be interested in a program that can lead, in the course of six years, to B.S., M.Eng. (Operations Research and Industrial Engineering), and M.B.A. degrees. See the section "Master of Engineering Degrees."

To ensure completion of the program in two semesters, the entering student should have completed courses in probability and statistics and in computer science, as well as four semesters of mathematics, through differential equations, linear algebra, and multivariate calculus.

Program requirements include a core of OR&IE courses plus technical electives chosen from a broad array of offerings. The choice of a particular elective sequence plus a specific project course results in completion of one of several options within the program. These include the applied operations research option, the manufacturing option, the financial engineering option, the systems engineering option, the information technology concentration, and the Semester in Manufacturing. These options are offered jointly with various other Cornell departments and schools and they provide the opportunity to interact on projects and in class with specialists in other engineering fields and in business. Many students select the applied operations research option, offered only by OR&IE, which has project teams made up entirely of OR&IE M.Eng. students and which offers the broadest choice of elective courses and career alternatives, in business and elsewhere. Students interested in an option other than the applied operations research option should obtain further information from the following: manufacturing option, Center for Manufacturing Enterprise, 207 Hollister Hall, 607-255-7757; financial engineering option and information technology option, 201 Frank H. T. Rhodes Hall, 607-255-9128; semester in manufacturing option, 304 Sage Hall, 607-255-4691; systems engineering option, 201 Frank H. T. Rhodes Hall, 607-255-9128. For students lacking an undergraduate degree in Operations Research, the financial engineering option, which is highly specialized, may entail additional prerequisites or more than two semesters.

I. For matriculants with preparation comparable to that provided by the undergraduate major in Operations Research and Engineering:

| *Fall term* | *Credits* |
|---|---|
| OR&IE 516, Case Studies | 1 |
| OR&IE 893, Applied OR&IE Colloquium | 1 |
| M.Eng. Project | 1 |
| Technical electives | 12 |
| *Spring term* | |
| OR&IE 894, Applied OR&IE Colloquium | 1 |
| M.Eng. Project | minimum of 4 |
| Technical electives | 10 |

II. For matriculants from other majors who minimally fulfill the prerequisite requirements (students who have the equivalent of OR&IE 520, 523, and 560 will take other OR&IE electives in their place):

| *Fall term* | *Credits* |
|---|---|
| OR&IE 560, Engineering Probability and Statistics II | 4 |
| OR&IE 520, Optimization I | 4 |
| OR&IE 522, Topics in Linear Optimization | 1 |
| OR&IE 516, Case Studies | 1 |
| OR&IE 580, Simulation Modeling and Analysis | 4 |
| OR&IE 893, Applied OR&IE Colloquium | 1 |
| M. Eng. Project | 1 |
| *Spring term* | |
| OR&IE 523, Introduction to Stochastic Processes I | 4 |
| OR&IE 894, Applied OR&IE Colloquium | 1 |
| M.Eng. Project | minimum of 4 |
| Technical electives | 5 |

For both of the above pro forma schedules, at least 12 credit hours of the specified electives must be chosen from the list of courses offered by the School of Operations Research and Industrial Engineering. For scheduling reasons, some options may require an additional summer, depending on the student's preparation.

The project requirement can be met in a variety of ways. Common elements in all project experiences include working as part of a group of three to five students on an engineering design problem, meeting with a faculty member on a regular basis, and oral and written presentation of the results obtained. Most projects address problems that actually exist in manufacturing firms, financial firms, and service organizations such as hospitals.

Additional program requirements are described in the *Master of Engineering Handbook*. For further details, see the contact information at the beginning of this section.

As part of their undergraduate ORE major or M.Eng. (ORIE) curriculum, students may study several subjects that are required for the Johnson Graduate School M.B.A. This early start on business-degree requirements may make it possible to get both the M.Eng. and the M.B.A. in two years, rather than the usual three. For details, see the subsection "Cooperative Program with the Johnson Graduate School of Management in the section "Master of Engineering Degrees," and contact the ORIE M.Eng. office, 201 Rhodes.

## MASTER OF ENGINEERING (SYSTEMS)

Offered by the System Engineering Program

Contact: 106 Rhodes Hall, 255-7757, www.systemseng.cornell.edu

The M.Eng. (Systems) degree program is a 30-credit (usually nine-course) curriculum designed to prepare students for professional practice. Applicants must hold an ABET-accredited (or equivalent) undergraduate degree in engineering. Those without such preparation will require course work beyond the graduate program's 30-credit minimum to fulfill the engineering preparation requirement. The general degree requirements and admissions information are described above in the section "Master of Engineering Degree Programs." Each student's program of study is designed individually in consultation with an academic adviser and approved by the director of graduate studies for systems.

The requirements are:

1. SYSEN 510 (Applied Systems Engineering), SYSEN 520 (System Architecture, Behavior, and Optimization), CEE 590 (Project Management), and a two-semester systems design project (SYSEN 590 or equivalent).
2. Electives from three categories of courses: Modeling and Analysis, Applications, and Systems Management. At least one course must be taken from the Modeling and Analysis category and at most one from the Systems Management category. A list of pre-approved electives is on the Systems Engineering web site.

## ENGINEERING COURSES

Courses offered in the College of Engineering are listed under the various departments and schools.

Courses are identified with a standard abbreviation followed by a three-digit number.

| | |
|---|---|
| Engineering Communications | ENGRC |
| Engineering Distribution | ENGRD |
| Engineering General Interest | ENGRG |
| Introduction to Engineering | ENGRI |
| Biological and Environmental Engineering | BEE |
| Applied and Engineering Physics | A&EP |
| Chemical and Biomolecular Engineering | CHEME |
| Civil and Environmental Engineering | CEE |
| Computer Science | COM S |
| Earth and Atmospheric Sciences | EAS |
| Electrical and Computer Engineering | ECE |
| Information Science | IS |
| Materials Science and Engineering | MS&E |
| Mechanical and Aerospace Engineering | M&AE |
| Nuclear Science and Engineering | NS&E |
| Operations Research and Industrial Engineering | OR&IE |
| Theoretical and Applied Mechanics | T&AM |

## ENGINEERING COMMON COURSES

### Engineering Communications Courses

Courses in this category, offered by the Engineering Communications Program (ECP), develop writing and oral-presentation skills needed by engineers.

**ENGRC 334 Independent Study in Engineering Communications**

Variable credits (1–3). Letter grade. By arrangement with instructor.

Members of the ECP occasionally give independent (also called "directed") studies in engineering communications, typically with students who are ready for advanced work in technical writing. A student doing a directed study works one-on-one with an ECP instructor to pursue an aspect of professional communications in more depth than is possible in the ECP's regular courses. Various types of projects are possible, e.g., studying forms of technical documentation, creating user manuals, analyzing and producing technical graphics, reading and writing about problems in engineering practice, and writing about technical topics for the public.

**ENGRC 335 Communications for Engineering Managers**

Fall, spring. 3 credits. Limited to 20 students per section. Designed for juniors and seniors. Prerequisite: two freshman writing seminars and field affiliation.

This seminar focuses on communications in organizational contexts common to engineering graduates. Topics may include internal and external communications; balancing visual and verbal elements in documents and oral presentations; teamwork and leadership; running and attending meetings; management strategies; and communicating with colleagues, superiors, subordinates, and clients. Students develop writing and management strategies that they apply in individual and team assignments. They learn how to organize technical and managerial information, articulate and support ideas, and communicate with technical and nontechnical audiences. (Note that absences are limited to three, after which sharp penalties occur.) Fulfills the college's technical-writing requirement. May be used as a Free or Approved Elective in expressive arts.

**ENGRC 350 Engineering Communications**

Fall and spring. 3 credits. Letter grade. 20 students per section. Designed for juniors and seniors. Prerequisite: two freshman writing seminars and field affiliation.

The ability to communicate well is a factor in being hired as well as being promoted; the higher an engineer rises, the more writing and presentation he/she will do. ENGRC 350 prepares students for these important activities. They write various types of documents (e.g., letters, memos, executive summaries, problem analyses, proposals, progress reports), give oral presentations, and incorporate graphics in both their oral and written work. Students learn how to communicate specialized information to different audiences (e.g., technical and nontechnical people, colleagues and clients, peers and supervisors, in-house departments, and government agencies), work in teams, and address organizational and ethical issues. The course material is drawn from professional contexts, principally engineering, and it generates lively discussion. The class size ensures close attention to each student's work. (Note that absences are limited to three, after which sharp penalties occur.) Fulfills the college's technical-writing requirement. May be used as a Free or Approved Elective in expressive arts.

## Engineering Distribution Courses

Courses in this category are sophomore-level courses cross-listed with a department. These courses are intended to introduce students to more advanced concepts of engineering and may require pre- or corequisites.

**ENGRD 201 Introduction to the Physics and Chemistry of the Earth (also EAS 201)**

Fall. 3 credits. Prerequisites: PHYS 112 or 207. J. Phipps Morgan, L. M. Cathles.

This course covers the formation of the solar system: accretion and evolution of the earth; the rock cycle: radioactive isotopes and the geological time scale, plate tectonics, rocks and minerals, earth dynamics, mantle plumes; the hydrologic cycle: runoff, floods and sedimentation, groundwater flow, contaminant transport; and the weathering cycle: chemical cycles, $CO_2$ (weathering), controls on global temperature ($CO_2$ or ocean currents), oil and mineral resources.

**ENGRD 202 Mechanics of Solids (also T&AM 202)**

Fall, spring. 4 credits. Prerequisite: PHYS 112, coregistration in MATH 192 or permission of instructor.

Covers: principles of statics, force systems, and equilibrium; frameworks; mechanics of deformable solids, stress, strain, statically indeterminate problems; mechanical properties of engineering materials; axial force, shearing force, bending moment, plane stress; bending and torsion of bars.

**ENGRD 203 Dynamics (also T&AM 203)**

Fall, spring. 3 credits. Prerequisite: ENGRD/T&AM 202, coregistration in MATH 293, or permission of instructor.

Newtonian dynamics of a particle, systems of particles, a rigid body. Kinematics, motion relative to a moving frame.. Impulse, momentum, angular momentum, energy. Rigid-body kinematics, angular velocity, moment of momentum, the inertia tensor. Euler equations, the gyroscope.

**ENGRD 210 Introduction to Circuits for Electrical and Computer Engineers (also ECE 210)**

Fall, spring. 3 or 4 credits. Corequisites: MATH 293 and PHYS 213. ECE majors must take 4 credits, includes a design project. Non-ECE majors can take 3 credits. All students must take a lab and a section. Fall, J. C. Belina, C. E. Seyler; spring, staff.

This is a first course in electrical circuits and electronics that establishes the fundamental properties of circuits with application to modern electronics. Topics include circuit analysis methods, operational amplifiers, basic filter circuits, and elementary transistor principles. The laboratory experiments are closely coupled with the lectures and there is a final design project.

**ENGRD 211 Computers and Programming (also COM S 211)**

Fall, spring, summer. 3 credits. Prerequisite: COM S 100 or an equivalent course in Java or C++.

Intermediate programming in a high-level language and introduction to computer science. Topics include program structure and organization, object-oriented programming (classes, objects, types, sub-typing), graphical user interfaces, algorithm analysis (asymptotic complexity, big "O" notation), recursion, data structures (lists, trees, stacks, queues, heaps, search trees, hash tables, graphs), simple graph algorithms. Java is the principal programming language.

**ENGRD 219 Mass and Energy Balances (also CHEME 219)**

Fall. 3 credits. Corequisite: physical chemistry or permission of instructor. W. L. Olbricht.

Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Introduction to phase equilibria for multicomponent systems.

**ENGRD 221 Thermodynamics (also M&AE 221)**

Fall, spring, may be offered summer. 3 credits. Prerequisites: MATH 192 and PHYS 112.

The definitions, concepts, and laws of thermodynamics. Topics considered include applications to ideal and real gases, vapor and gas power systems, refrigeration, and heat pump systems. Combustion and chemical equilibrium. Examples and problems are related to contemporary aspects of power generation and broader environmental issues.

**ENGRD 230 Introduction to Digital Logic Design**

Fall, spring. 4 credits. Prerequisite: COM S 100. Fall, W. E. Swartz, D. L. Long; spring, staff.

Introduction to the design and implementation of practical digital circuits. Topics include transistor network design, Boolean algebra, combinational circuits, sequential circuits, finite state machine design, and analog and digital converters. Design methodology using both discrete components and hardware description languages is covered in the weekly laboratory portion of the course.

**ENGRD 241 Engineering Computation (also CEE 241)**

Spring. 3 credits. Prerequisites: COM S 100 and MATH 293. Corequisite: MATH 294. (Completion of MATH 294 is suggested.) C. A. Shoemaker.

Introduction to numerical methods, numerical mathematics, and probability and statistics. Development of programming and graphics proficiency with MATLAB and spreadsheets. Numerical analysis topics considered are: accuracy, precision, Taylor-series approximations, truncation and round-off errors, condition numbers, operation counts, convergence, and stability. Included are numerical methods for solving engineering problems that entail roots of functions, simultaneous linear equations, regression, curve fitting, interpolation, numerical differentiation and integration, and ordinary and partial differential equations. Introduction to finite difference and finite element methods. Applications are drawn from different areas of engineering.

**ENGRD 251 Engineering for a Sustainable Society (also BEE 251)**

Fall. 3 credits. Corequisite: MATH 293.

Case studies of contemporary environmental issues including pollutant distribution in natural systems, air quality, hazardous waste management, and sustainable development. Emphasis is on the application of mathematics, physics, and engineering sciences to solve energy and mass balances in environmental sciences. Students are introduced to the basic chemistry, ecology, biology, ethics, and environmental legislation relevant to the particular environmental problem.

**ENGRD 252 The Physics of Life (also A&EP 252)**

Fall. Prerequisites: MATH 192, CHEM 207 or 211, and co-registration in or completion of PHYS 213. L. Pollack.

This course introduces the physics of biological macromolecules (e.g., proteins, DNA, RNA) to students of the physical sciences or engineering who have little or no background in biology. The macromolecules are studied from three perspectives. First, the biological role or function of each class of macromolecules is considered. Second, a quantitative description of the physical interactions that determine the behavior of these systems is provided. Finally, techniques that are commonly used to probe these systems, with an emphasis on current research, are discussed.

**ENGRD 260 Principles of Biological Engineering (also BEE 260)**
Fall. 3 credits. Corequisite: MATH 293.
Focuses on the integration of biological systems with engineering, math, and physical principles. Students learn how to formulate equations for biological systems in class and then practice it in homework sets. Topic areas range from molecular principles of reaction kinetics and molecular binding events to macroscopic applications, such as energy and mass balances of bioprocessing and engineering design of implantable sensors.

**ENGRD 261 Mechanical Properties of Materials: From Nanodevices to Superstructures (also MS&E 261)**
Fall. 3 credits. S. P. Baker.
The mechanical properties of materials (strength, stiffness, toughness, ductility, and so on) and their physical origins are examined. The relationship of the elastic, plastic, and fracture behavior to microscopic structure in metals, ceramics, polymers, and composite materials is explored. Effects of time and temperature on materials properties are discussed. The emphasis of this course is on considerations for design and optimum performance of materials and engineered objects.

**ENGRD 262 Electronic Materials for the Information Age (also MS&E 262)**
Fall. 3 credits. Prerequisite: MATH 192; corequisite PHYS 213 or permission of instructor. G. Malliaras.
The course examines the electrical and optical properties of materials. Topics covered include the mechanism of electrical conduction in metals, semiconductors and insulators, the tuning of electrical properties in semiconductors, the transport of charge across metal/semiconductor and semiconductor/semi-conductor junctions, and the interaction of materials with light. Applications in electrophotography, solar cells, electronics, and display technologies are discussed.

**ENGRD 264 Computer-Instrumentation Design (also A&EP 264)**
Fall, spring. 3 credits. Prerequisite: COM S 100. 1 lec, 1 lab. Not open (without instructor's permission) to seniors. T. Cool.
Covers the use of a small computer in an engineering or scientific research laboratory. The experiments and devices investigated include: analog to digital converters (ADC), digital to analog converters (DAC), digital input/output (I/O), counter/timers, serial port communications, digital temperature control, error analysis, nonlinear least squares fitting of experimental data, viscosity of fluids, a robot arm, and thermal diffusion. Both C++ programming and graphical programming with LabVIEW™ are used for computer interfacing to hardware. A second goal of the course is to develop effective written communication skills in the context of science and engineering. Students prepare progress reports, technical reports, and formal articles based on the experiments.

**ENGRD 270 Basic Engineering Probability and Statistics**
Fall, spring, summer. 3 credits. Prerequisites: MATH 191 and 192.
This course gives students a working knowledge of basic probability and statistics and their application to engineering. Computer analysis of data and simulation are included. Topics include random variables, probability distributions, expectation, estimation, testing, experimental design, quality control, and regression.

**[ENGRD 321 Numerical Methods in Computational Molecular Biology (also BIOBM 321 and COM S 321)**
Fall. 3 credits. Prerequisites: at least one course in calculus such as MATH 106, 111, or 191 and a course in linear algebra such as MATH 221 or 294 or BTRY 417. COM S 100 or equivalent and some familiarity with iteration, arrays, and procedures.
An introduction to numerical computing using MATLAB organized around five applications: the analysis of protein shapes, dynamics, protein folding, score functions, and field equations. Students become adept at plotting, linear equation solving, least squares fitting, and cubic spline interpolation. More advanced problem-solving techniques that involve eigenvalue analysis, the solution of ordinary and partial differential equations, linear programming, and nonlinear minimization are also treated. The goal of the course is to develop a practical computational expertise with MATLAB and to build mathematical intuition for the problems of molecular biology. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.]

**ENGRD 322 Introduction to Scientific Computation (also COM S 322)**
Spring, summer. 3 credits. Prerequisites: COM S 100 and MATH 222 or 294.
An introduction to elementary numerical analysis and scientific computation. Topics include interpolation, quadrature, linear and nonlinear equation solving, least-squares fitting, and ordinary differential equations. The MATLAB computing environment is used. Vectorization, efficiency, reliability, and stability are stressed. Special lectures cover parallel computation. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

## Courses of General Interest

Courses in this category are of general interest and cover technical, historical, and social issues relevant to the engineering profession. These courses may also include seminar or tutorial type courses.

**ENGRG 100J Cooperative Workshop for COM S 100J**
Fall, spring. 1 credit. S-U grades only. Concurrent registration in COM S 100J required.
Academic Excellence Workshop for COM S 100J. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in COM S 100J.

**ENGRG 100M Cooperative Workshop for COM S 100M**
Fall, spring. 1 credit. S-U grades only. Concurrent registration in COM S 100M required.
Academic Excellence Workshop for COM S 100M. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in COM S 100M.

**ENGRG 150 Engineering Seminar**
Fall. 1 credit. First-year students only. S-U grades only.
Engineering freshmen meet weekly with their faculty advisers to discuss a range of engineering topics. Discussions may include the engineering curriculum and student programs, what different types of engineers do, the character of engineering careers, active research areas in the college and in engineering in general, and study and examination skills useful for engineering students. Groups may visit campus academic, engineering, and research facilities.

**ENGRG 190 Cooperative Workshop for MATH 190**
Fall. 1 credit. S-U grades only. Concurrent registration in MATH 190 required.
Academic Excellence Workshop for MATH 190. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 190.

**ENGRG 191 Cooperative Workshop for MATH 191**
Fall. 1 credit. S-U grades only. Concurrent registration in MATH 191 required.
Academic Excellence Workshop for MATH 191. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 191.

**ENGRG 192 Cooperative Workshop for MATH 192**
Fall, spring. 1 credit. S-U grades only. Concurrent registration in MATH 192 required.
Academic Excellence Workshop for MATH 192. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 192.

**ENGRG 210 Cooperative Workshop for COM S 211**
Fall, spring. 1 credit. S-U grades only. Concurrent registration in COM S 211 required.
Academic Excellence Workshop for COM S 211. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in COM S 211.

**ENGRG 211 Cooperative Workshop for CHEM 211**
Fall, spring. 1 credit. S-U grades only. Concurrent registration in CHEM 211 required.
Academic Excellence Workshop for CHEM 211. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course

material, designed to enhance understanding of core concepts in CHEM 211.

**[ENGRG 250 Technology in Society (also ECE 250, HIST 250, S&TS 250)**

Fall. 3 credits. A humanities elective for engineering students. Not offered 2004–2005.

This course investigates the history of technology in Europe and the United States from ancient times to the present. Topics include the economic and social aspects of industrialization; the myths of heroic inventors like Morse, Edison, and Ford; the government's regulation of technology; the origins of mass production; and the spread of the automobile and microelectronics cultures in the United States.]

**ENGRG 293 Cooperative Workshop for MATH 293**

Fall, spring. 1 credit. S-U grades only. Concurrent registration in MATH 293 required.

Academic Excellence Workshop for MATH 293. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 293.

**ENGRG 294 Cooperative Workshop for MATH 294**

Fall, spring. 1 credit. S-U grades only. Concurrent registration in MATH 294 required.

Academic Excellence Workshop for MATH 294. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 294.

**ENGRG 298 Inventing an Information Society (also AM ST 292, ECE 298, S&TS 292, and HIST 292)**

Spring. 3 credits. Approved for humanities distribution. Cannot be taken for credit after ENGRG 198/ECE 198. R. R. Kline.

Explores the history of information technology from the 1830s to the present by considering the technical and social history of telecommunications, the electric-power industry, radio, television, computers, and the Internet. Emphasis is placed on the changing relationship between science and technology, the economic aspects of innovation, gender and technology, and other social relations of this technology.

**ENGRG 323 Engineering Economics and Management (also CEE 323)**

Spring, usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. Student must register under CEE 323. D. P. Loucks.

Introduction to engineering and business economics and to project management. Intended to give students a working knowledge of money management and how to make economic comparisons of alternative engineering designs or projects. The impact of inflation, taxation, depreciation, financial planning, economic optimization, project scheduling, and legal and regulatory issues are introduced and applied to economic investment and project-management problems.

**ENGRG 357 Engineering in American Culture (also AM ST 356, S&TS 357, and HIST 357)**

Fall. 4 credits. Approved for humanities distribution. R. R. Kline.

The history of engineering in the United States from 1800 to the present. We investigate the education of engineers, how engineering changed from a masculine profession to one more open to women, the building of monumental projects, public images of the engineer, enthusiasm and disasters, and engineering in a global setting.

**ENGRG 360 Ethical and Social Issues in Engineering (also S&TS 360)**

Spring. 3 credits. Open to sophomores. R. R. Kline.

Studies major ethical and social issues involved in engineering practice. The issues include responsibility for designing products that do not harm public health, safety, and welfare; rights of engineers in large corporations; risk analysis and the principle of informed consent; conflict of interest; whistleblowing; trade secrets; and broader concerns such as environmental degradation, cost of health care, computer ethics, and working in multinational corporations. Codes of ethics of the professional engineering societies, ethical theory, and the history and sociology of engineering are introduced to analyze these issues.

**ENGRG 461 Entrepreneurship for Engineers (also M&AE 461, OR&IE 452)**

Fall. 3 credits. Enrollment open to upperclass engineers; others with permission of instructor.

For description, see M&AE 461.

**ENGRG 678 Teaching Seminar**

Fall, spring. 1 credit. S-U grades only.

Independent Study promoting reflection on teaching styles and experiences for teaching assistants in the College of Engineering. Participants must be concurrently fulfilling a TA assignment. Requirements include: participation in the College of Engineering's TA Development Program, consisting of an initial one and one-half day training session, followed by one evening microteaching session early in the semester; participation in the TA midterm evaluation process, followed by a formal feedback session with program staff; and completion of a reflective journal on teaching experiences. All components are designed to provide TAs with the opportunity to process their understanding of teaching and learning through the formulation of questions, concepts, and theories related to their experiences.

## Introduction to Engineering Courses

Courses in this category are freshman-level courses intended to introduce students to various aspects of engineering. They have no prerequisites and are always cross-listed with a department.

**ENGRI 101 Introduction to Biomedical Engineering Analysis (also BMEP 101)**

Spring. 1 credit. Requires concurrent registration in BIO G 110. Lec and lab. D. Grubb and S. Archer.

This class is integrated with BIO G 110 to provide examples of engineering analysis of biological topics described in BIO G 110. Emphasis on molecular, cellular, and physiological systems.

**ENGRI 102 Introduction to Nanoscience and Nanoengineering (also A&EP 102)**

Fall, spring. 3 credits.

Lecture/laboratory course designed to introduce freshmen to some of the ideas and concepts of nanoscience and nanotechnology. Topics covered include nanoscience and nanotechnology—what they are and why they are of interest; atoms and molecules; the solid state; surfaces; behavior of light and material particles when confined to nanoscale dimensions; scanning tunneling microscopy (STM), atomic force microscopy (AFM), microelectromechanical systems (MEMS) design; basic micromachining and chemical synthesis methods, i.e., "top-down" and "bottom-up" approaches to nanofabrication; how to manipulate structures on the nanoscale; physical laws and limits they place on the nanoworld; some far-out ideas. In the laboratory, students will use an AFM to record atomic resolution images, use a MEMS computer-aided design software package to model the entire manufacturing sequence of a simple MEMS device, examine the simulated behavior of the device and compare it with real behavior, construct a simple STM and learn through hands on experience the basic workings of the device.

**ENGRI 110 Lasers and Photonics (also A&EP 110)**

Fall. 3 credits. A. Gaeta.

Lasers have had an enormous impact on communications, medicine, remote sensing, and material processing. In this course we review the properties of light that are essential to understanding the underlying principles of lasers and these photonic technologies. There also is a strong, hands-on laboratory component in which the students build and operate a nitrogen laser and participate in several demonstration experiments such as holography, laser processing of materials, optical tweezers, and fiber optics.

**ENGRI 111 Nanotechnology (also MS&E 111)**

Fall. 3 credits. E. Giannelis.

Nanotechnology has been enabling the Information Revolution with the development of even faster and more powerful devices for manipulation, storing, and transmitting information. In this hands-on course students learn how to design and manipulate materials to build devices and structures in applications ranging from computers to telecommunications to biotechnology.

**ENGRI 112 Introduction to Chemical Engineering (also CHEME 112)**

Fall. 3 credits. Limited to freshmen. T. M. Duncan.

Design and analysis of processes involving chemical change. Students learn strategies for design, such as creative thinking, conceptual blockbusting, and (re)definition of the design goal, in the context of contemporary chemical and biomolecular engineering. Includes methods for analyzing designs, such as mathematical modeling, empirical analysis by graphics, and dynamic scaling through dimensional analysis, to assess product quality, economics, safety, and environmental issues.

**ENGRI 113 Solving Environmental Problems for Urban Regions (also CEE 113)**

Spring. 3 credits. M. L. Weber-Shirk.

Learn how to design: reservoirs to provide water during droughts, aqueducts to transport water, and water treatment plants to prevent waterborne diseases. Take field trips, build a computer-controlled miniature water treatment plant, and explore new technologies for making safe drinking water.

**ENGRI 115 Engineering Applications of Operations Research**

Fall, spring. 3 credits. Enrollment not open to OR&IE upper-class majors.

An introduction to the problems and methods of Operations Research and Industrial Engineering focusing on problem areas (including inventory, network design, and resource allocation), the situations in which these problems arise, and several standard solution techniques. In the computational laboratory, students encounter problem simulations and use some standard commercial software packages.

**ENGRI 116 Modern Structures (also CEE 116)**

Fall. 3 credits. M. J. Sansalone.

An introduction to structural engineering in the 21st century—the challenges structural engineers face and the innovative approaches they are using to address them. Using case studies of famous structures, students learn to identify different structural forms and understand how various forms carry load-using principles of statics, mechanics, and material behavior. In addition, the historical, economic, social, and political context for each structure is discussed. Case studies of failures are used to explain how structures fail in earthquakes and other extreme events, and students are introduced to analytical and experimental approaches (shake table and wind tunnel testing) to quantifying loads on structures subjected to extreme events. Types of structures considered include skyscrapers, bridges, aircraft, and underground structures. Includes a project to design, analyze, build, and test a structure subjected to dynamic loads.

**ENGRI 117 Introduction to Mechanical Engineering (also M&AE 117)**

Fall. 3 credits. 2 lectures and 1 lab per week.

An introduction to fundamentals of engineering, with emphasis on mechanical and aerospace engineering. The lectures will cover a little from each aspect of mechanical and aerospace engineerings applied to how to design and analyze products or devices and their performance. Students learn and understand materials characteristics, the behavior of materials, and material selection for performing engineering function. They also learn fundamentals of fluid mechanics, heat transfer, automotive engineering, engineering design and product development, patents and intellectual property, and engineering ethics. There will be a final project in which students use the information learned to design and manufacture a product.

**ENGRI 118 Design Integration: A Portable CD Player (also MS&E 118 and T&AM 118)**

Spring. 3 credits. W. Sachse.

This course examines the roles of various engineering disciplines on the design of a portable compact disc (CD) player. Students are introduced to elements of mechanical, electrical, materials, environmental, manufacturing, and computer engineering as related to the CD player. Laboratory sessions and demonstrations are used to illustrate the principles of design.

**ENGRI 119 Biomaterials for the Skeletal System (also MS&E 119)**

Fall. 3 credits. D. T. Grubb.

Biomaterials are at the intersection of biology and engineering. This course explores natural structural materials in the human body, their properties and microstructure, and their synthetic and semi-synthetic replacements. Bones, joints, teeth, tendons, and ligaments are used as examples, with their metal, plastic, and ceramic replacements. Topics covered include strength, corrosion, toxicity, wear, and bio-compatibility. Case studies of design lead to consideration of regulatory approval requirements and legal liability issues.

**ENGRI 122 Earthquake! (also EAS 122)**

Spring. 3 credits. L. D. Brown.

The science of natural hazards and strategic resources is explored. This course covers techniques for locating and characterizing earthquakes, and assessing the damage they cause; methods of using sound waves to image the earth's interior to search for strategic materials; and the historical importance of such resources. Includes seismic experiments on campus to probe for groundwater, the new critical environmental resource.

**ENGRI 124 Designing Materials for the Computer (also MS&E 124)**

Spring. 3 credits. 3 lectures.

Introduces the materials, processes, and properties of the semiconductors, polymers, ceramics, and metals used in the microelectronics industry to form integrated circuits, electronic devices, and displays. This course examines lithographic processing, metallization, diffusion, ion implantation, oxidation, and other processes used in fabricating electronic devices and their packages. The technology of displays is discussed, including liquid crystal displays and light-emitting devices.

**ENGRI 126 Introduction to Signals and Telecommunications**

Spring. 3 credits. D. F. Delchamps.

This course introduces the concepts that underlie wired and wireless communication systems. Students achieve a rudimentary understanding of basic ideas such as coding and data compression; frequency content, bandwidth, and filtering; sampling and reconstruction; and time- and frequency-division multiplexing. Discussions of practical applications focus on areas such as the public switched telephone network, ISDN, ATM, and TCP/IP. Students also develop an appreciation for the historical development of the field. The course includes both lectures and laboratory demonstrations.

**ENGRI 127 Introduction to Entrepreneurship and Enterprise Engineering (also M&AE 127)**

Spring. 3 credits. Open to all Cornell students regardless of major. No prerequisites.

This course provides a solid introduction to the entrepreneurial process to students in engineering. The main objective is to identify and to begin to develop skills in the engineering work that occurs in high-growth, high-tech ventures. Basic engineering management issues, including the entrepreneurial perspective, opportunity recognition and evaluation, and gathering and managing resources are covered. Technical topics such as the engineering design process, product realization, and technology forecasting are discussed.

**ENGRI 165 Computing in the Arts (also, CIS 165, COM S 165)**

Fall. 3 credits. S-U grade optional. Complements ART 171+ and MUSIC 120+.

For description, see CIS 165.

**ENGRI 167 Visual Imaging in the Electronic Age (also CIS 167, COM S 167)**

Spring. 3 credits. S-U grade optional.

For description, see CIS 167

**[ENGRI 172 Computation, Information, and Intelligence (also COGST 172 and COM S 172)**

Fall. 3 credits. Prerequisites: some knowledge of differentiation required, permission of instructor required for students who have completed the equivalent of COM S 100. Not offered 2004–2005.

An introduction to computer science using methods and examples from the field of artificial intelligence. Topics include game playing, search techniques, learning theory, compute-intensive methods, data mining, information retrieval, the web, natural language processing, machine translation, and the Turing test. This is not a programming course; rather, "pencil and paper" problem sets will be assigned. Some calculus required.]

**[ENGRI 185 Art, Archaeology, and Analysis (also EAS 200, and MS&E 285)**

Spring. 3 credits. Not offered 2004–2005. R. Kay.

An interdepartmental course on the use of techniques of science and engineering in cultural research. Includes applications of physical and physiological principles to the study of archaeological artifacts and works of art. Also covers historical and technical aspects of artistic creation. Students learn analyses by modern methods to deduce geographical origins, and for exploration, dating, and authentication of cultural objects. Does not meet liberal studies distribution requirement for Engineering.]

# APPLIED AND ENGINEERING PHYSICS

J. D. Brock, director; B. R. Kusse, associate director for undergraduate studies; F. W. Wise, director of graduate studies; R. A. Buhrman, T. A. Cool, H. G. Craighead, A. L. Gaeta, V. O. Kostroun, M. Lindau, R. V. E. Lovelace, D. Muller, L. Pollack, J. Silcox, W. W. Webb, C. Xu; adjunct faculty: D. H. Bilderback; senior research associate: E. J. Kirkland; instructor: M. J. Plisch; instructor: L. Wickham

**A&EP 102 Introduction to Nanoscience and Nanoengineering (also ENGRI 102)**

Spring. 3 credits.

This is a course in the Introduction to Engineering series. For description, see ENGRI 130.

**A&EP 110 Lasers and Photonics (also ENGRI 110)**

Fall. 3 credits. A. Gaeta.

This is a course in the Introduction to Engineering series. For description, see ENGRI 110.

**A&EP 217 Electricity and Magnetism (also PHYS 217)**

Fall, spring. 4 credits. Prerequisites: approval of student's adviser and permission of the instructor; co-registration in PHYS 216 or knowledge of special relativity at the level of PHYS 116; MATH 192 or equivalent and co-registration in MATH 293 or equivalent. Staff.

Intended for students who have done well in PHYS 112 or 116 (or the equivalent) and in mathematics who desire a more analytic treatment than that of PHYS 213. At the level of Electricity and Magnetism by Purcell. Recommended for prospective engineering physics majors. A placement quiz may be given early in the semester, permitting those student who find the material too abstract or analytical to transfer into PHYS 213 without difficulty.

**A&EP 252 The Physics of Life (also ENGRD 252)**

Fall. Prerequisites: MATH 192, CHEM 207 or 211, and co-registration in or completion of PHYS 213. L. Pollack.

For description, see ENGRD 252.

**A&EP 264 Computer-Instrumentation Design (also ENGRD 264)**

Fall, spring. 3 credits. Prerequisites: COM S 100. 1 lec, 1 lab. not open (without instructor's permission) to seniors.

For description, see ENGRD 264.

**A&EP 321 Mathematical Physics I**

Fall, summer. 4 credits. Prerequisite: MATH 294. Intended for upper-level undergraduates in the physical sciences. B. Kusse.

Review of vector analysis; complex variable theory, Cauchy-Rieman conditions, complex Taylor and Laurent series, Cauchy integral formula and residue techniques, conformal mapping; Fourier Series; Fourier and Laplace transforms; ordinary differential equations; separation of variables. Texts: Mathematical Methods for Physicists, by Arfken; Mathematical Physics, by Butkov.

**A&EP 322 Mathematical Physics II**

Spring. 4 credits. Prerequisite: A&EP 321. Second of the 2-course sequence in mathematical physics intended for upper-level undergraduates in the physical sciences. B. Kusse.

Topics: partial differential equations, Bessel functions, spherical harmonics, separation of variables, wave and diffusion equations, Laplace, Helmholtz, and Poisson's Equations, transform techniques, Green's functions; integral equations, Fredholm equations, kernals; complex variables, theory, branch points and cuts, Riemann sheets, method of steepest descent; tensors, contravariant, and covariant representations; group theory, matrix representations, class and character. Texts: *Mathematical Methods for Physicists*, by Arfken; *Mathematical Physics*, by Butkov.

**A&EP 324 Maple Supplement to Mathematical Physics 321 and 322**

Spring. 1 credit. R. V. E. Lovelace.

The course gives a broad introduction to Maple in applications to problems of mathematical physics similar to those covered in A&EP 321 and 322. We use Maple to solve differential equations—both linear and nonlinear. We make extensive use of plotting capabilities of Maple. Additionally, we cover matrices, complex functions, Laplace and Fournier transforms (and FFTs), and group theory. We also give an introduction to LaTex.

**A&EP 330 Modern Experimental Optics (see also PHYS 330)**

Fall. 4 credits. Enrollment limited. Prerequisites: PHYS 214 or equivalent. E. Bodenschatz.

A practical laboratory course in basic and modern optics. The various projects cover a wide range of topics from geometrical optics to classical wave properties such as interference, diffraction, and polarization. Each experimental setup is equipped with standard, off-the-shelf optics and opto-mechanical components to provide the students with hands-on experience in practical laboratory techniques currently employed in physics, chemistry, biology, and engineering. Students are also introduced to digital imaging and image processing techniques.

**A&EP 333 Mechanics of Particles and Solid Bodies**

Fall, summer. 4 credits. Prerequisites: PHYS 112 or 116 and coregistration in A&EP 321 or equivalent or permission of instructor.

This course covers: Newton's mechanics; constants of the motion; many-body systems; linear oscillations; variational calculus; Lagrangian and Hamiltonian formalism for generalized coordinates; non-inertial reference systems; central-force motion; motion of rigid bodies; small vibrations in multi-mass systems; nonlinear oscillations; and basic introduction to relativistic mechanics. Emphasis is on mathematical treatments, physical concepts, and applications. (On the level of *Classical Dynamics*, by Marion and Thorton.)

**A&EP 355 Intermediate Electromagnetism**

Fall, summer. 4 credits. Prerequisites: PHYS 214 or 217 and coregistration in A&EP 321 or equivalent, or permission of instructor.

Topics: vector calculus, electrostatics, analytic and numerical solutions to Laplace's equation in various geometries, electric and magnetic multipoles, electric and magnetic materials, energy in fields, quasistatics, and magnetic circuit design. Emphasis is on developing proficiency with analyical and numerical solution techniques in order to solve real-world design problems.

**A&EP 356 Intermediate Electrodynamics**

Spring. 4 credits. Prerequisite: A&EP 355 and coregistration in A&EP 322 or equivalent, or permission of instructor.

Topics: electromagnetic waves, waveguides, transmission lines, dispersive media, radiation, special relativity, interference phenomena. Emphasis is on physical concepts and developing ability to design/analyze microwave circuits and antenna arrays.

**A&EP 361 Introductory Quantum Mechanics**

Spring. 4 credits. Prerequisites: A&EP 333 or PHYS 318; coregistration in A&EP 322 or equivalent and in A&EP 356 or PHYS 326.

A first course in the systematic theory of quantum phenomena. Topics include wave mechanics, the Dirac formalism, angular momentum, the hydrogen atom, and perturbation theory.

**A&EP 363 Electronic Circuits (also PHYS 360)**

Fall, spring. 4 credits. Prerequisites: PHYS 208 or 213 or permission of the instructor. No previous experience with electronics assumed; however, the course moves quickly through some introductory topics such as basic DC circuits. Fall term usually less crowded. 1 lec, 2 labs. Fall: E. Kirkland; spring: J. Alexander.

Analyze, design, build and experimentally test circuits used in scientific and engineering instrumentation (with discrete components and integrated circuits). Analog circuits: resistors, capacitors, operational amplifiers (linear amplifiers with feedback, oscillators, comparators), filters, diodes and transistors. Digital circuits: combinatorial (gates) and sequential (flip-flops, counters, shift registers) logic. Computer interfacing introduced and used to investigate digital to analog (DAC) and analog to digital conversion (ADC) and signal averaging.

**A&EP 423 Statistical Thermodynamics**

Fall. 4 credits. Prerequisite: introductory 3-semester physics sequence plus 1 year of junior-level mathematics.

Quantum statistical basis for equilibrium thermodynamics, microcanonical, canonical and grand canonical ensembles, and partition functions. Classical and quantum ideal gases, paramagnetic and multiple-state systems. Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics and applications. Introduc-tion to systems of interacting particles. At the level of *Thermal Physics*, by Kittel and Kroemer, and *Statistical Physics*, by Rosser.

**A&EP 434 Continuum Physics**

Spring. 4 credits. Prerequisites: A&EP 333 and 356 or equivalent.

Topics: Elasticity and Fluid Mechanics: basic phenomena of elasticity, simple beams, stress and strain tensors, materials equations, equations of motion, general beam equations, waves; fluids: basic phenomena, Navier Stokes equation, scaling laws, Reynolds and Froude numbers, Poisseuille flows, Stokes drag on sphere, boundary layers, invicid and incompressible flows, potential flow, conservation laws, Bernoulli equation, vorticity and circulation, life of wings, jets, instabilities, introduction to turbulence. Projects in combination with AEP 438 possible. At the level of Lai, Rubin and Krempl, *Continuum Mechanics*, and Tritton, *Introduction to Fluid Mechanics*.

**A&EP 438 Computational Engineering Physics**

Spring. 3 credits. Prerequisites: COM S 100, A&EP 321, 333, 355, 361, or equivalent, or permission of instructor; coregistration in 361 permitted.

Numerical computation (derivatives, integrals, differential equations, matrices, boundary-value problems, relaxation, Monte Carlo methods, etc.) is introduced and applied to engineering physics problems that cannot by solved analytically (three-body problem, electrostatic fields, quantum energy levels, etc.). Computer programming required (in C or optionally C++, FORTRAN, or Pascal). Some prior exposure to programming assumed but no previous experience with C assumed.

**A&EP 440 Quantum and Nonlinear Optics**

Spring. 4 credits. Prerequisites: A&EP 356, A&EP 361, or equivalent.

An introduction to the fundamentals of the interaction of laser light with matter. Topics include the propagation of laser beams in bulk media and guided-wave structures, the origins of optical nonlinearities, harmonic generation, self-focusing, optical bistability, propagation of ultrashort pulses, solitons, optical phase conjugation, optical resonance and two-level atoms, atom cooling and trapping, multiphoton processes, spontaneous and simulated scattering, and ultra-intense laser-matter interactions.

**A&EP 450 Introductory Solid State Physics (also PHYS 454)**

Fall. 4 credits. Prerequisites: some exposure to quantum mechanics at the level of PHYS 443, A&EP 361, or CHEM 793 is highly desirable but not absolutely required.

An introduction to the physics of crystalline solids. Covers crystal structures; electronic states; lattice vibrations; and metals, insulators, and semiconductors. Computer simulations of the dynamics of electrons and ions in solids. Optical properties, magnetism, and superconductivity are covered as time allows. The majority of the course addresses the foundations of the subject, but time is devoted to modern and/or technologically important topics such as quantum size effects. At the level of *Introduction to Solid State Physics* by Kittel or *Solid State Physics* by Ashcroft and Mermun.

**A&EP 470 Biophysical Methods (also BIONB 470)**

Spring. 3 credits. Prerequisites: solid knowledge of basic physics and mathematics through the sophomore level; some knowledge of cellular biology helpful but not required. Letter grades only.

An overview of the diversity of modern biophysical experimental techniques used in the study of biophysical systems at the cellular and molecular level. Topics covered include methods that examine both structure and function of biological systems, with emphasis on the applications of these methods to biological membranes. The course format includes assigned literature reviews by the students on specific biophysics topics and individual student presentations on these topics. The course is intended for students of the engineering, physics, chemistry, and biological disciplines who seek an introduction to modern biophysical experimental methods.

**A&EP 484 Introduction to Controlled Fusion: Principles and Technology (also ECE 484, M&AE 459, and NS&E 484)**

Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students. Offered on demand.

For description, see NS&E 484.

**A&EP 490/491 Independent Study in Engineering Physics**

Fall, spring. Credit TBA.

Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the faculty. The study can take a number of forms; for example, design of laboratory apparatus, performance of laboratory measurements, computer simulation or software developments, theoretical design and analysis. Details TBA with respective faculty member.

**A&EP 550 Applied Solid State Physics**

Spring. 3 credits. Prerequisites: A&EP 356, 361, 423, 450 (or equivalent).

Directed at students who have had an introductory course in solid state physics at the level of Kittel. This course concentrates on the application of the quantum mechanical theory of solid state physics to semiconductor materials, solid state electronic devices, solid state detectors and generators of electro-magnetic radiation, superconducting devices and materials, the nonlinear optical properties of solids, ferromagnetic materials, nanoscale devices, and mesoscopic quantum mechanical effects. The course stresses the basic, fundamental physics underlying the applications rather than the applications themselves. At the level of *Introduction to Applied Solid State Physics* by Dalven.

**A&EP 607 Advanced Plasma Physics (also ECE 582)**

Spring. 4 credits. Prerequisites: ECE 581 and A&EP 606. Offered on demand.

For description, see ECE 582.

**A&EP 633 Nuclear Reactor Engineering (also NS&E 633)**

Fall. 4 credits. Prerequisite: introductory course in nuclear engineering. Offered on demand. K. B. Cady.

For description, see NS&E 633.

**A&EP 661 Nanocharacterization**

Fall. 3 credits. Prerequisites: Fourier transforms, basic electromagnetism, and undergraduate quantum mechanics or chemistry. Undergraduates should consult with the instructor before enrolling in this class.

A graduate-level introduction to the tools used to image and probe optical, electronic, chemical, and mechanical properties at the nanoscale and below. Discussion centers on the physics of the interaction processes used for characterization, quantification, and interpretation of the collected signals, common artifacts, the engineering tradeoffs made in constructing the actual instruments, and the fundamental detection limits for each method. Topics include the interaction of electrons, ions, and photons with materials; scanned probe and force microscopy; scanning and transmission electron microscopy; x-ray microanalysis; electron energy loss spectroscopy; and a brief survey of non-imaging methods such as RBS, XPS, and SIMS.

**A&EP 662 Micro/Nano-fabrication and Processing**

Spring. 3 credits.

An introduction to the fundamentals of micro- and nano-fabricating and patterning thin-film materials and surfaces, with emphasis on electronic and optical materials, micro-mechanics, and other applications. Vacuum and plasma thin-film deposition processes. Photon, electron, X-ray, and ion-beam lithography. Techniques for pattern replication by plasma and ion processes. Emphasis is on understanding the physics and materials science that define and limit the various processes. At the level of Brodie and Muray.

**A&EP 663 Nanobiotechnology (also BIO G 663 and MS&E 563)**

Spring. 3 credits. Letter grade only. C. Batt.

Upper level undergraduate and graduate-level course that covers the basics of biology and the principles and practice of microfabrication techniques. The course focuses on applications in biomedical and biological research. A team design project that stresses interdisciplinary communication and problem solving is one of the course requirements. The course is held twice weekly with 75-minute classes. All lectures are teleconferenced to our NBTC associate institutes.

**[A&EP 711 Principles of Diffraction (also MS&E 671)**

Fall. 3 credits. Letter grades only. Not offered 2004–2005. J. D. Brock.

This course is a graduate-level introduction to diffraction/scattering phenomena in the context of solid-state and soft condensed-matter systems. The primary topic is using the scattering and absorption of neutron, electron, and X-ray beams to study physical systems. Particular emphasis is placed on issues related to synchrotron X-ray sources. Specific topics that are covered in the course include: elastic and inelastic scattering; diffraction from two- and three-dimensional periodic lattices; the Fourier representation of scattering centers and the effects of thermal vibrations and disorder; diffraction, reflectivity, or scattering from surface layers; diffraction or scattering from gases and amorphous materials; small angle scattering; X-ray absorption spectroscopy; resonant (e.g., magnetic) scattering; novel techniques using coherent X-ray beams; and a survey of dynamical diffraction from perfect and imperfect lattices.]

**A&EP 751 M ENG Project**

Fall, spring. 6–12 credits TBA. Required for candidates for the M.Eng. (Engineering Physics) degree.

Independent study under the direction of a member of the university faculty. Students participate in an independent research project through work on a special problem related to their field of interest. A formal and complete research report is required.

**A&EP 753 Special Topics Seminar in Applied Physics**

Fall. 1 credit. Prerequisite: undergraduate physics. Required for candidates for the M.Eng. (Engineering Physics) degree and recommended for seniors in engineering physics.

Special topics in applied science, with focus on areas of applied physics and engineering that are of current interest. Subjects chosen are researched in the library and presented in a seminar format by the students. Effort is made to integrate the subjects within selected subject areas such as atomic, biological, computational, optical, plasma, and solid-state physics, or microfabrication technology, as suggested by the students and coordinated by the instructor.

**A&EP 781 Advanced Plasma Physics I: Cosmic Plasma Physics (also ECE 681)**

Fall. 3 credits. R. Lovelace.

The course uses the text *Cosmic Plasma Physics* by Boris Somov and covers the following topics: charged particles and EM fields, statistical description of plasma, distribution functions and the Vaslov equation, propagation of particles, motion of particles in given fields, wave particle interactions, Coulomb collisions, hydrodynamic description of plasmas, magnetohydrodynamic description of plasmas, and cosmic plasma flows.

**A&EP 782 Advanced Plasma Physics (also ECE 682)**
Spring. 3 credits. Prerequisite: ECE 581. C. E. Seyler
For description, see ECE 682.

## BIOLOGICAL AND ENVIRONMENTAL ENGINEERING

M. F. Walter, chair; B. A. Ahner, L. D. Albright, D. J. Aneshansley, A. J. Baeumner, J. A. Bartsch, J. R. Cooke, A. K. Datta, K. G. Gebremedhin, D. A. Haith, J. B. Hunter, L. H. Irwin, W. J. Jewell, D. Luo, J.-Y. Parlange, N. R. Scott, R. M. Spanswick, T. S. Steenhuis, M. B. Timmons, L. P. Walker

For complete course descriptions, see the Biological and Environmental Engineering listing in the College of Agriculture and Life Sciences section or visit the department web site, www.bee.cornell.edu.

**BEE 151 Introduction to Computing**
Fall. 4 credits. Prerequisite: MATH 191 or equivalent (coregistration permissible). Each lab and recitation section limited to 22 students.

**BEE 200 The BEE Experience**
Spring. 1 credit.

**BEE 222 Bioengineering Thermodynamics and Kinetics**
Spring. 3 credits. Prerequisites: MATH 192, BIO 100, PHYS 213, and one course in chemistry.

**BEE 251 Engineering for a Sustainable Society (also ENGRD 251)**
Fall. 3 credits. Corequisite: MATH 293.

**BEE 260 Principles of Biological Engineering (also ENGRD 260)**
Fall. 3 credits. Corequisite: MATH 293.

**BEE 299 Sustainable Development: A Web-Based Course**
Spring. 3 credits. Prerequisite: sophomore standing and above. S-U grades optional.

**BEE 301 Renewable Energy Systems**
Spring. 3 credits. Prerequisite: college physics.

**BEE 325 Environmental Management**
Fall. 3 credits.

**BEE 350 Biological and Environmental Transport Processes**
Fall. 3 credits. Prerequisites: MATH 293 and fluid mechanics (coregistration permissible).

**BEE 360 Molecular and Cellular Bioengineering (also BMEP 360)**
Spring. 3 credits. Prerequisite: biochemistry or A&EP 252.

**BEE 365 Properties of Biological Materials**
Spring. 3 credits. Prerequisites: ENGRD 202 (coregistration permissible).

**BEE 368 Biotechnology Applications: Animal Bioreactors**
Fall. 3 credits. Prerequisite: biochemistry or permission of instructor.

**BEE 371 Physical Hydrology for Ecosystems**
Spring. 3 credits. Prerequisite: 1 course in calculus.

**BEE 427 Water Sampling and Measurement**
Fall. 3 credits. Prerequisites: soils and/or fluids or hydrology courses and MATH 191.

**BEE 435 Principles of Aquaculture**
Spring. 3 credits. Prerequisite: minimum junior standing.

**BEE 450 Bioinstrumentation**
Spring. 4 credits. Prerequisites: linear differential equations, physics or electrical science, computer programming, and use of spreadsheets.

**BEE 453 Computer-Aided Engineering: Applications to Biomedical Processes (also M&AE 453)**
Spring. 3 credits. Prerequisite: heat and mass transfer (BEE 350 or equivalent).

**BEE 454 Physiological Engineering**
Fall. 3 credits. Corequisite: fluid mechanics.

**BEE 456 Biomechanics of Plants (also BIO PL 456)**
Fall. 3 credits. Prerequisites: upper division undergraduate or graduate status, completion of introductory sequence in biology, and 1 year of calculus, or permission of instructor. S-U grades optional.

**BEE 459 Biosensors and Bioanalytical Techniques**
Spring. 4 credits. Prerequisites: biochemistry or permission of instructor.

**BEE 464 Bioseparation Processes**
Fall. 3 credits. Prerequisites: biochemistry, physics, MATH 112 or 192, BEE 260, or permission of instructor.

**BEE 471 Introduction to Groundwater (also CEE 431 and EAS 445)**
Spring. 3 credits. Prerequisites: MATH 293, fluid mechanics or hydrology course.
For description, see CEE 431.

**BEE 473 Watershed Engineering**
Fall. 3 credits. Prerequisite: fluid mechanics or hydrology.

**BEE 474 Water and Landscape Engineering Applications**
Spring. 3 credits. Prerequisite: fluid mechanics, hydrology, or permission of instructor.

**BEE 475 Environmental Systems Analysis**
Fall. 3 credits. Prerequisites: computer programming and 1 year of calculus.

**BEE 476 Solid Waste Engineering**
Spring. 3 credits. Prerequisites: 1 semester of physics and chemistry.

**BEE 478 Ecological Engineering**
Spring. 3 credits. Prerequisite: junior-level environmental quality engineering course or equivalent.

**BEE 481 LRFD-Based Engineering of Wood Structures (also CEE 481)**
Spring. 3 credits. Prerequisite: ENGRD 202.

**BEE 484 Metabolic Engineering**
Spring. 3 credits. Prerequisites: biochemistry or permission of instructor.

**BEE 487 Sustainable Energy Systems**
Spring. 3 credits. Prerequisites: BEE 350 and thermodynamics.

**BEE 489 Engineering Entrepreneurship, Management and Ethics**
Spring. 3 credits. Prerequisites: ENGRD 270 or CEE 304 or equivalent, junior standing.

**BEE 493 Technical Writing for Engineers**
Fall, spring. 1 credit. Corequisite: BEE 450/473.

**BEE 494 Special Topics in Biological and Environmental Engineering**
Fall, spring. 1–4 credits. S-U grades optional.

**BEE 495 BEE Honors Research**
Fall, spring. 1–6 credits. Prerequisites: enrollment in the BEE Honors Research Program.

**BEE 496 Capstone Design in Biological and Environmental Engineering**
Fall, spring. 1–3 credits. Corequisite: BEE 473 or BEE 478, or BEE 481 and permission of instructor. Completed independent study form (available in 140 Roberts Hall) is required to register.

**BEE 497 Individual Study in Biological and Environmental Engineering**
Fall, spring. 1–4 credits. Prerequisite: written permission of instructor and adequate ability and training for the work proposed. Normally reserved for seniors in upper two-fifths of their class. S-U grades optional. Completed independent study form (available in 140 Roberts Hall) is required to register.

**BEE 498 Undergraduate Teaching**
Fall, spring. 1–4 credits. Prerequisite: written permission of instructor. Completed independent study form (available in 140 Roberts Hall) is required to register.

**BEE 499 Undergraduate Research**
Fall, spring. 1–4 credits. Prerequisites: written permission of instructor; adequate training for work proposed. Normally reserved for seniors in upper two-fifths of their class. Completed independent study form (available in 140 Roberts Hall) is required to register.

**BEE 501 Bioengineering Seminar (also BMEP 501)**
Fall, spring. 1 credit. For junior, senior, and graduate students only.

**BEE 551/552 Agricultural and Biological Engineering Design Project**
Fall, 551; spring, 552. 3–6 credits. Prerequisite: admission to the M.Eng. (Agricultural and Biological) degree program.

**BEE 625 Environmental Management**
Fall. 3 credits. Prerequisite: graduate standing.

**BEE 647 Water Transport in Plants**
Fall. 2 credits. Offered alternate years.

**BEE 649 Solute Transport in Plants**
Fall. 2 credits. Offered alternate years.

**BEE 651 Bioremediation: Engineering Organisms to Clean Up the Environment**
Spring. 3 credits. Prerequisites: BIOMI 290 or BIOMI 398 or BIOMI 331 or permission of instructor.

**BEE 652 Instrumentation: Sensors and Transducers**
Spring. 3 credits. Prerequisites: linear differential equations, introductory chemistry and introductory physics, or permission of instructor.

**BEE 655 Thermodynamics and Its Applications**
Spring. 3 credits. Prerequisite: MATH 293 or equivalent.

**BEE 659 Biosensors and Bioanalytical Techniques**
Spring. 4 credits. Prerequisites: biochemistry and permission of instructor.

**BEE 671 Analysis of the Flow of Water and Chemicals in Soils**
Fall. 3 credits. Prerequisites: 4 calculus courses and fluid mechanics.

**BEE 672 Drainage**
Spring. 4 credits. Prerequisites: BEE 471 or BEE 473. S-U grades optional.

**BEE 673 Sustainable Development Seminar (also NBA 573)**
Spring. 1–3 credits. Prerequisite: upper division undergraduate and graduate students or permission of instructor.

**BEE 678 Nonpoint Source Models**
Spring. 3 credits. Prerequisites: computer programming and calculus.

**BEE 685 Biological Engineering Analysis**
Spring. 4 credits. Prerequisite: T&AM 310 or permission of instructor.

**BEE 687 Sustainable Bio-based Industries**
Fall. 1 credit. Prerequisite: graduate standing.

**BEE 694 Graduate Special Topics in Agricultural and Biological Engineering**
Fall, spring. 1–4 credits. S-U grades optional.

**BEE 697 Graduate Individual Study in Agriculture and Biological Engineering**
Fall, spring. 1–6 credits. Prerequisite: permission of instructor. S-U grades optional.

**BEE 700 General Seminar**
Fall. 1 credit. S-U grades only.

**BEE 750 Orientation to Graduate Study**
Fall. 1 credit. S-U grades only. Limited to newly joining graduate students.

**BEE 754 Watershed Management**
Spring. 2–3 credits. Prerequisite: graduate standing or permission of instructor.

**BEE 760 Nucleic Acid Engineering (also BMEP 760)**
Fall. 3 credits. Prerequisite: BEE 360 or permission of instructor.

**BEE 771 Soil and Water Engineering Seminar**
Fall, spring. 1–3 credits. Prerequisite: graduate status or permission of instructor. S-U grades optional.

**BEE 781 Structures and Related Topics Seminar**
Spring. 1 credit. Prerequisite: graduate status or permission of instructor. S-U grades only.

**BEE 785 Biological Engineering Seminar**
Spring. 1 credit. Prerequisite: graduate status or permission of instructor. S-U grades only.

**BEE 787 Industrial Ecology of Agriculturally Based Bioindustries**
Spring. 3 credits. Prerequisites: 1 year calculus, matlab, BEE 687, graduate standing.

**BEE 788 Biomass Conversion of Energy and Chemicals**
Fall. 3 credits. Prerequisites: one year of college calculus and a minimum of one course in thermodynamics and computer programming.

**BEE 800 Master's-Level Thesis Research**
Fall, spring. 1–15 credits. Prerequisite: permission of adviser. S-U grades only.

**BEE 900 Doctoral-Level Thesis Research**
Fall, spring. 1–15 credits. Prerequisite: permission of adviser. S-U grades only.

# BIOMEDICAL ENGINEERING

Michael L. Shuler, chair; Donald L. Bartel, associate director; William Lee Olbricht, director of graduate studies; Larry Bonassar, David Putnam

**BMEP 101 Introduction to Biomedical Engineering Analysis (also ENGRI 101)**
Spring. 1 credit. Requires concurrent registration in BIO G 110. Lecture and laboratory. D. Grubb and S. Archer.
For description, see ENGRI 101.

**BMEP 301 Molecular Principles of Biomedical Engineering (also CHEME 401)**
Fall. 3 credits. Prior course work in BIO G 110, BIO BM 330, BIO MI 290 or equivalent. Lec and lab. S. Archer and staff.
Introduction to genomics, proteomics, bioinformatics, and computational biology with an emphasis on the engineering challenges for these areas. Cytoskeletal and motor proteins and their relationship to nano- and micro-machines and nanobiotechnology. Existing and emerging technologies and instrumentation critical to molecular-level analysis in biomedical engineering.

**BMEP 302 Cellular Principles of Biomedical Engineering (also CHEME 402)**
Spring. 3 credits. Prerequisite: BMEP 301 or prior course work in BIO G 110, BIOBM 330, BIOMI 290 or equivalent plus mathematics through differential equations (e.g., MATH 221 or 294), or permission of instructor. Lecture and laboratory. D. A. Putnam, S. Archer.
Integration of mammalian cell biology with engineering modeling principles, put into the context of medical pathology and disease states. Three modules comprising: 1) cell culture techniques/receptor ligand interactions, 2) cellular trafficking, and 3) signal transduction.

**BMEP 330 Introduction to Computational Neuroscience (also BIONB 330, PSYCH 330, and COGST 330)**
Fall. 3 credits. Limited to 25 students.
For description, see BIONB 330.

**BMEP 360 Molecular and Cellular Bioengineering (also BEE 360)**
Spring. 3 credits. Prerequisite: biochemistry or A&EP 252.
For description, see BEE 360.

**BMEP 401 Biomedical Engineering Analysis of Metabolic and Structural Systems (also M&AE 466)**
Fall. 3 credits. Prerequisite: prior course work in basic biology. Prior course work in solid mechanics and fluid mechanics is highly recommended. Lec and lab. L. Bonassar, S. Archer.
This course presents the quantitative biology of the renal, respiratory, cardiovascular, and musculoskeletal systems. Mathematical modeling of physiological processes involving mechanics and transport in solid and fluid organs is included.

**BMEP 402 Information Exchange in Biomedical Engineering Systems**
Spring. 3 credits. Prerequisite: BMEP 401 or permission of instructor. Lec and lab. Staff.
Quantitative biology of the endocrine, nervous, and immune systems. Computation and mathematics of neural nets, communication among macroscale biocommunication systems.

**BMEP 404 CDE in Biomedical System Design (also ECE 402)**
Spring. 1–4 credits. Co- or prerequisites: at least one of ECE 425, ECE 476, ECE 453. J. C. Belina.
For description, see ECE 402.

**[BMEP 440 Electronics in Neurobiology (also BIONB 440)**
Fall. 4 credits. Limited to juniors, seniors, and graduate students. Prerequisite: a calculus course. S-U grades optional. Offered alternate years. B. R. Land.
For description, see BIONB 440.]

**BMEP 441 Computer in Neurobiology (also BIONB 441)**
Fall. 4 credits. Limited to juniors, seniors, and graduate students. Prerequisite: a calculus course. S-U grades optional. Offered alternate years. B. R. Land.
For description, see BIONB 441.

**BMEP 463 Neuromuscular Biomechanics (also M&AE 463)**
Spring. 3 credits. Prerequisite: ENGRD 202 and 203, or permission of instructor. Offered alternate years.
For description, see M&AE 463.

**BMEP 464 Orthopaedic Tissue Mechanics (also M&AE 464)**
Spring. 3 credits. Prerequisites: ENGRD 202 and M&AE 325 or permission of instructor. Offered alternate years.
For description, see M&AE 464.

**BMEP 481 Biomedical Engineering (also CHEME 481)**
Spring. 3 credits. Prerequisite: CHEME 324 or equivalent or permission of instructor. W. L. Olbricht.
For description, see CHEME 481.

**BMEP 491 Principles of Neurophysiology (also BIONB 491)**
Spring. 4 credits. Limited to 20 students. Prerequisite: BIONB 222 or written permission of instructor. S-U grades optional for graduate students with permission of instructor. B. R. Johnson.
For description, see BIONB 491.

**BMEP 501 Bioengineering Seminar (also BEE 501)**
Fall, spring. 1 credit. For juniors, seniors, and graduate students only. Staff.
Broad survey of all aspects of bioengineering, including biomedical, bioprocess, biological, and bioenvironmental engineering and aspects of biotechnology. Sessions may be technical presentations or discussions. Sessions may occasionally be held outside of scheduled times.

**BMEP 539 Biomedical Materials and Devices for Human Body Repair (also TXA 439)**
Spring. 2–3 credits. Prerequisites: college Natural Science requirement (Chem. or Biol). C. C. Chu.
For description, see TXA 439. Extra project required; same lectures as TXA 439.

**BMEP 550 Product Engineering and Design in Biomedical Engineering**
Spring. 3 credits. Prerequisite: graduate standing with priority given to M.Eng. students majoring in BMEP. D. L. Bartel.
Students learn how to design biomedical devices and develop therapeutic strategies within the bounds of health care economics, the needs of patients and physicians, the regulatory environment for medical devices and pharmaceuticals, and stringent ethical standards of biomedical engineering practice.

**BMEP 565 Biomechanical Systems—Analysis and Design (also M&AE 565)**
Fall. 3 or 4 credits. Prerequisites: undergraduate courses in dynamics and strength of materials (e.g., T&AM/ENGRD 202 and 203) and senior standing, graduate standing, or permission of instructor.
For description, see M&AE 565.

**BMEP 570 Biophysical Methods (also BIONB 470 and A&EP 470)**
Spring. 3 credits. Prerequisites: solid knowledge of basic physics and mathematics through the sophomore level; some knowledge of cellular biology helpful but not required. Letter grades only.
For description, see A&EP 470.

**BMEP 578 Computer Analysis of Biomed Images (also ECE 578)**
Spring. 4 credits. Prerequisite: permission of instructor. A. P. Reeves.
For description, see ECE 578

**BMEP 591 Design Project**
Fall, spring. 3–6 credits. Students are encouraged to register for two terms as a continuing course. Required for M. Eng. students majoring in BME.
Design and economic evaluation of a biomedical engineering device or therapeutic strategy. Team projects are encouraged.

**BMEP 607 Principles of Magnetic Resonance Imaging (MRI)**
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor. Y. Wang.
Physical principles and engineering techniques of MRI. Applications in human medicine. Co-taught with Weill Medical College.

**BMEP 631 Engineering Principles for Drug Delivery (also CHEME 631)**
Fall. 3 credits. Prerequisites: graduate standing and background in organic and polymer chemistry or permission of instructor.
Application of engineering design principles to problems in drug formulation and delivery. Specific topics include traditional drug formulation, mechanisms and kinetics of pharmaceutical stability, stimuli-sensitive systems, controlled release devices, prodrugs, targeted drug delivery, biomaterials, gene therapy, and governmental regulatory issues.

**BMEP 663 Advanced Topics in Neuromuscular Biomechanics (also M&AE 663)**
Spring. 3 credits. Permission of instructor only. Offered alternate years. F. Valero-Cuevas.
For description, see M&AE 663.

**[BMEP 664 Mechanics of Bone (also M&AE 664)**
Spring. 3 credits. Prerequisites: graduate standing or permission of instructor. Offered alternate years. Not offered 2004–2005.
For description, see M&AE 664.]

**BMEP 665 Principles of Tissue Engineering (also M&AE 665 and MS&E 665)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.
This course covers introductory concepts in tissue engineering, including polymeric biomaterials used for scaffolds, mechanisms of cell-biomaterial interaction, biocompatibility and foreign body response, cell engineering, and tissue biomechanics. This knowledge is applied to engineering of several body systems, including the musculoskeletal system, cardiovascular tissues, the nervous system, and artificial organs. These topics are discussed in the context of scale-up, manufacturing, and regulatory issues.

**BMEP 703 Graduate Student Teaching Experience**
Fall, spring. Variable credit. S-U grades optional. Staff.
Guided individual experience in laboratory instruction and/or lectures/recitation instruction. Provides a preparatory teaching experience for graduate students considering an academic career.

**BMEP 711 Fundamentals of Biomedical Engineering Research I**
Fall. 3 credits. Prerequisite: graduate standing. Priority is given to MS/PhD graduate students with a major or minor in BME. Staff.
First part of a two-semester sequence that introduces students to a variety of subjects in biomedical engineering including nanobiotechnology, biomechanics, systems and computational biology, biomaterials, tissue engineering, statistics, and experimental design. The course also covers associated subjects including professional development, ethics, writing a scientific paper, authorship issues, patents, technology transfer, conflicts of interest, and preparing a research proposal. The course is a combination of lectures and discussions, with students taking an active role in the instruction.

**BMEP 712 Fundamentals of Biomedical Engineering Research II**
Spring. 3 credits. Prerequisite: BMEP 711 or permission of instructor. Staff.
Continuation of BMEP 711.

**BMEP 716 Immersion Experience in Medical Research and Clinical Practice**
Summer. 6 credits. Prerequisite: open to PhD students in BME. D. L. Bartel.
A six-week immersion at Weill Medical College. Students participate in lectures, rounds, and seminars; observe surgeries; and solve medical problems presented by the staff.

**[BMEP 731 Advanced Biomedical Engineering Analysis of Biological Systems**
Fall. 3 credits. Prerequisite: graduate standing. Priority given to MS/PhD and M.Eng. students majoring in BMEP. Not offered 2004–2005. Staff.
The fundamentals of quantitative analysis of biological systems. The course illustrates analytical methods applicable to a variety of biological systems, ranging from molecular to cellular to organ to application of whole-body systems.]

**BMEP 760 Nucleic Acid Engineering (also BEE 760)**
Spring. 3 credits. Prerequisite: BEE 360 or permission of instructor.
For description, see BEE 760.

**BMEP 790 Biomedical Engineering Seminar**
Fall, spring. 1 credit. Prerequisite: graduate standing. Staff.
Research-based seminars. May meet concurrently with other seminar series as appropriate.

**BMEP 890 MS Thesis Research**
Fall, spring. Variable credit.
Thesis research for the M S. degree in BME.

**BMEP 990 Ph.D. Thesis Research**
Fall, spring. Variable Credit.
Thesis research for the PhD degree in BME.

## CHEMICAL AND BIOMOLECULAR ENGINEERING

P. Clancy, director; A. B. Anton, L. A. Archer, A. M. Center, C. Cohen, M. P. Delisa, T. M. Duncan, J. R. Engstrom, F. A. Escobedo, Y. L. Joo, D. L. Koch, K. H. Lee, W. L. Olbricht, D. Putnam, M. L. Shuler, P. H. Steen, A. D. Stroock

**CHEME 112 Introduction to Chemical Engineering (also ENGRI 112)**
Fall. 3 credits. Limited to freshmen. T. M. Duncan.
This is a course in the Introduction to Engineering series. For description, see ENGRI 112.

**CHEME 219 Mass and Energy Balances (also ENGRD 219)**
Fall. 3 credits. Corequisite: physical or organic chemistry or permission of instructor. W. L. Olbricht.
For description, see ENGRD 219.

**CHEME 301 Nonresident Lectures**
Spring. 1 credit. P. Clancy.
Lecturers from industry and from selected departments of the university provide information to assist students in their post-graduate plans.

**CHEME 313 Chemical Engineering Thermodynamics**
Fall. 3 credits. Prerequisite: physical chemistry II. F. A. Escobedo.

A study of the first and second laws and their consequences for chemical systems. Thermodynamic properties of pure fluids, solids, and mixtures; phase and chemical reaction equilibrium; heat effects in batch and flow processes; and power cycles and refrigeration.

**CHEME 323 Fluid Mechanics**
Spring. 3 credits. Prerequisites: CHEME 219 and engineering mathematics sequence. D. L. Koch.
Fundamentals of fluid mechanics. Macroscopic and microscopic balances. Applications to problems involving viscous flow.

**CHEME 324 Heat and Mass Transfer**
Fall. 3 credits. Prerequisite: CHEME 323. C. Cohen.
Fundamentals of heat and mass transfer. Macroscopic and microscopic balances. Applications to problems involving conduction, convection, and diffusion.

**CHEME 332 Analysis of Separation Processes**
Spring. 3 credits. Prerequisites: CHEME 313 and 324. Y. L. Joo.
This course covers the analysis of separation processes involving phase equilibria and mass transfer. Topics include phase equilibria; equilibrium-based separations; rate-based separation processes (membrane separations, sorption operations); introduction to bioseparations and process simulators; choosing a separation option; and the design and synthesis of separation processes.

**CHEME 372 Introduction to Process Dynamics and Control**
Spring. 2 credits. Prerequisites: CHEME 313 and 323. A. B. Anton.
Modeling and analysis of the dynamics of chemical processes, Laplace transforms, block diagrams, feedback control systems, and stability analysis.

**CHEME 390 Reaction Kinetics and Reactor Design**
Spring. 3 credits. Prerequisites: CHEME 313 and 323. J. R. Engstrom.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

**CHEME 391 Physical Chemistry II (also CHEM 391)**
Spring. 4 credits. Limited to engineering students. T. M. Duncan.
For description, see CHEM 391.

**CHEME 401 Molecular Principles of Biomedical Engineering (also BMEP 301)**
Fall. 3 credits. Prerequisites: BIO G 110 or BIO BM 330. K. H. Lee.
For description, see BMEP 301.

**CHEME 402 Cellular Principles of Biomedical Engineering (also BMEP 302)**
Spring. 3 credits. D. Putnam.
For description, see BMEP 302.

**CHEME 432 Chemical Engineering Laboratory**
Fall. 4 credits. Prerequisites: CHEME 323, 324, 332, and 390. A. M. Center and staff.
Laboratory experiments in fluid dynamics, heat and mass transfer, separations, other operations. Correlation and interpretation of data. Technical report writing.

**CHEME 462 Chemical Process Design**
Spring. 4 credits. Prerequisite: CHEME 432. A. M. Center and staff.
Students prepare a full-scale feasibility study of a chemical process including product supply and demand forecasts, process design including reaction system design, separations scheme development, heat integration via application of pinch technology, and economic analysis of the process. Students develop presentation and teamwork skills through weekly presentations.

**CHEME 470 Process Control Strategies**
Spring. 3 credits. A. M. Center.
Introduction to how control concepts are represented, control valve sizing and selection, process control strategies, dynamic response of process systems as it relates to control loop tuning, statistical process control, advanced process control methods both for chemical and biological processes and programmable logic controllers and distributed control systems.

**CHEME 472 Feedback Control Systems (also ECE 472 and M&AE 478)**
Fall. 4 credits. Prerequisites: CHEME 372, ECE 301, M&AE 326, or permission of instructor. A. B. Anton and R. D'Andrea.
For description, see M&AE 478.

**CHEME 480 Chemical Processing of Electronic Materials**
Spring. 3 credits. A. B. Anton.
Introduction to chemical processing of semiconductor materials for the manufacture of microelectronic devices, with specific emphasis on thermodynamics, transport phenomena, and kinetics. Topics include semiconductor properties and behavior, microelectronic device operation, thermochemistry of deposition and etching reactions, vacuum transport, plasmas, PVD, oxidation, diffusion, CVD, and statistical process control.

**CHEME 481 Biomedical Engineering (also BMEP 481)**
Spring. 3 credits. Prerequisite: CHEME 324 or equivalent or permission of instructor. W. L. Olbricht.
Special topics in biomedical engineering, including cell separations, blood flow, design of artificial devices, biomaterials, image analysis, biological transport phenomena, pharmacokinetics and drug delivery, biomedical transducers (ECG and pace makers), and analysis of physiological processes such as adhesion, mobility, secretion, and growth.

**CHEME 484 Microchemical and Microfluidic Systems**
Fall. 3 credits. Prerequisite: CHEME 390 or permission of instructor. J. R. Engstrom.
Principles of chemical kinetics, thermodynamics, and transport phenomena applied to microchemical and microfluidic systems. Applications in distributed chemical production, portable power, micromixing, separations, and chemical and biological sensing and analysis. Fabrication approaches (contrasted with microelectronics), transport phenomena at small dimensions, modeling challenges, system integration, case studies.

**CHEME 490 Undergraduate Projects in Chemical Engineering**
Fall, spring. Variable credit.
Research or studies on special problems in chemical engineering.

**CHEME 491 Undergraduate Teaching in Chemical Engineering**
Fall. 1 credit. T. M. Duncan and M. Ackley.
Methods of instruction in chemical engineering acquired through discussions with faculty and by assisting with the instruction of freshmen and sophomores.

**CHEME 520 Chemical, Polymer, Biomedical, and Electronic Materials Processing**
Fall, spring. 1–6 credits (1 credit per section).

**520.1 An Overview of Chemical Processing**
Spring. 1 credit. Meets first third of term. Limited to nonchemical engineers. T. M. Duncan.
An introduction to chemical engineering design and analysis-mathematical modeling, graphical methods and dynamic scaling. Open to nonchemical engineers only.

**520.2 Introduction to Biomedical Engineering**
Spring. 1 credit. Meets first third of term. W. L. Olbricht.
Meets concurrently with CHEME 481.

**520.3 Introduction to Electronic Materials Processing**
Spring. 1 credit. Meets first third of term. A. B. Anton.
Meets concurrently with CHEME 480.

**520.4 Introduction to Polymer Processing**
Spring. 1 credit. Meets second third of term. L. A. Archer.
Overview and simple quantitative analyses of several plastic processes with an emphasis on the role of rheology in polymer processing.

**520.5 Chemical Engineering Tools and Equipment**
Spring. 1 credit. Meets first third of term. A. M. Center.
An introduction to the hardware used in chemical engineering processes and a discussion of how these mechanical devices are configured to meet their process objectives. Also includes an introduction to the evaluation techniques and trouble-shooting methods frequently used by chemical engineers.

**520.6 Introduction to Petroleum Refining**
Fall. 1 credit. Meets second third of term. A. M. Center.
The petroleum refining industry including crude oil evaluation, fuel quality, refining processes, refinery configurations, and refinery economics.

**CHEME 543 Bioprocess Engineering**
Fall. 3 credits. Prerequisite: CHEME 390 or permission of instructor. No prior background in the biological sciences required. M. L. Shuler.
A discussion of principles involved in using microorganisms, tissue cultures, and enzymes for processing. Primary emphasis is on production of biopharmaceuticals, but biological waste treatment and medical systems are also considered.

**CHEME 565 Design Project**
Fall, spring. 3 or 6 credits. Required for students in the M.Eng. (Chemical) program.
Design study and economic evaluation of a chemical processing facility, alternative methods of manufacture, raw-material preparation, food processing, waste disposal, or some other aspect of chemical processing.

**CHEME 572 Managing New Business Development**

Fall. 3 credits. Prerequisites: graduate standing; undergraduates must have permission of instructor. A. M. Center.

A case study approach introduces the typical fundamental factors driving a business venture, examines how to develop implementation strategies for the venture, and teaches the project management skills necessary to successfully implement the venture.

**CHEME 590 Special Projects in Chemical Engineering**

Fall, spring. Variable credit. Limited to graduate students.

Nonthesis research or studies on special problems in chemical engineering.

**CHEME 631 Engineering Principles for Drug Delivery (also BMEP 631)**

Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.

For description, see BMEP 631.

**CHEME 640 Polymeric Materials**

Fall. 3 credits. C. Cohen.

Chemistry and physics of the formation and characterization of polymers. Principles of fabrication.

**CHEME 644 Aerosols and Colloids**

Fall. 3 credits. D. Koch.

Dynamics of micro- and nano-particles, which contain many molecules but are small enough that molecular effects are important. Topics include the formation and growth of particles; their transport, rheological, and phase behaviors; and their role in technologies including paints, foods, health-care products, drug delivery, composite materials, and air pollution control.

**CHEME 661 Air Pollution Control**

Spring. 3 credits. P. H. Steen.

Origin of air pollutants, U.S. emission standards, dispersion equations. Design of equipment for removal of particulate and gaseous pollutants formed in combustion and chemical processing.

**CHEME 675 Synthetic Polymer Chemistry (also MS&E 622 and CHEM 671)**

Fall. 4 credits. Prerequisites: CHEM 359–360 or equivalent or permission of instructor.

For description, see CHEM 671.

**CHEME 711 Advanced Chemical Engineering Thermodynamics**

Fall. 3 credits. Prerequisite: CHEME 313 or equivalent. P. Clancy and A. B. Anton.

Postulatory approach to thermodynamics. Legendre transformations. Equilibrium and stability of general thermodynamic systems. Applications of thermodynamic methods to advanced problems in chemical engineering. Introduction to statistical mechanical ensembles, phase transitions, Monte Carlo methods, and theory of liquids.

**CHEME 713 Chemical Kinetics and Transport**

Spring. 5 credits. Prerequisite: CHEME 390 or equivalent. F. Escobedo and A. Stroock.

Topics include microscopic and macroscopic viewpoints; connections between phenomenological chemical kinetics and molecular reaction dynamics; reaction cross sections, potential energy surfaces, and dynamics of bimolecular collisions; molecular beam scattering; transition state theory. Unimolecular reaction dynamics; complex chemically reacting systems: reactor stability, multiple steady states, oscillations, and bifurcation; reactions in heterogeneous media; and free-radical mechanisms in combustion and pyrolysis.

**CHEME 731 Advanced Fluid Mechanics and Heat Transfer**

Fall. 3 credits. Prerequisites: CHEME 323 and 324 or equivalent. Y. L. Joo.

Topics include derivation of conservation equations; conductive heat transfer; low Reynolds number fluid dynamics; lubrication theory; inviscid fluid dynamics; boundary layer theory; forced convection; and introduction to non-Newtonian fluid mechanics (polymeric liquids and suspensions), microfluidics, stability analysis, and turbulent flow.

**CHEME 741 Selected Topics in Biochemical Engineering**

Fall, spring. 1 credit (may be repeated for credit). Prerequisite: permission of instructor. K. H. Lee and M. L. Shuler.

Discussion of current topics and research in biochemical engineering for graduate students.

**[CHEME 745 Physical Polymer Science I**

Fall. 3 credits. Corequisite: CHEME 711 or equivalent. Offered alternate years; next offered 2005–2006. C. Cohen.

Covers thermodynamic properties of dilute, semidilute, and concentrated solutions from both classical and scaling approaches. Also covers characterization techniques of dilute solutions: osmometry, light scattering, viscometry, and sedimentation. Covers rubber elasticity; mechanical and thermodynamic properties of gels. Includes discussion of polymer melts: equations of state and glass transition phenomena.]

**CHEME 751 Mathematical Methods of Chemical Engineering Analysis**

Fall. 4 credits. D. L. Koch.

Application of advanced mathematical techniques to chemical engineering analysis. Mathematical modeling, scaling, regular and singular perturbations, multiple scales, asymptotic analysis, linear and nonlinear ordinary and partial differential equations, statistics, data analysis, and curve fitting.

**CHEME 753 Analysis of Nonlinear Systems: Stability, Bifurcation, and Continuation**

Fall. 3 credits. Prerequisite: CHEME 751 or equivalent. Offered alternate years. P. H. Steen.

Topics include elements of stability and bifurcation theory; branch-following techniques; stability of discrete and continuous systems; and application to elasticity, reaction-diffusion, and hydrodynamic systems using software for continuation problems.

**CHEME 790 Seminar**

Fall, spring. 1 credit each term.

General chemical engineering seminar required of all graduate students in the field of chemical and biomolecular engineering.

**CHEME 890 Thesis Research**

Fall, spring. Variable credit.

Thesis research for the M.S. degree in chemical engineering.

**CHEME 990 Thesis Research**

Fall, spring. Variable credit.

Thesis research for the Ph.D. degree in chemical engineering.

# CIVIL AND ENVIRONMENTAL ENGINEERING

J. M. Gossett, director; W. D. Philpot, associate director; J. F. Abel, W. Aquino, L. Banks-Sills, J. J. Bisogni, Jr., W. H. Brutsaert, P. G. Carr, E. A. Cowen, R. A. Davidson, R. I. Dick, L. B. Dworsky, K. Gebremedhin, M. D. Grigoriu, D. A. Haith, K. C. Hover, A. R. Ingraffea, F. H. Kulhawy, L. W. Lion, P. L-F. Liu, D. P. Loucks, J. R. Mbwana, W. McGuire, A. H. Meyburg, L. K. Nozick, T. D. O'Rourke, K. D. Papoulia, T. Pekoz, P. Petrina, C. ReVelle, R. E. Richardson, M. J. Sansalone, R. E. Schuler, C. A. Shoemaker, J. R. Stedinger, H. E. Stewart, C. H. Trautmann, M. A. Turnquist, F. Wayno, M. Weber-Shirk, R. N. White

Courses in the School of Civil and Environmental Engineering are offered in three broad mission areas: Civil Infrastructure, Environment, and Engineering Systems and Management. Within each mission area are several areas of specialization. The following are the course numbers and titles listed by specialization within each mission area. Some courses are listed in two or more mission areas because the course content is relevant to multiple areas. The school also offers a number of general courses that are not unique to one mission area. Full course descriptions follow in the subsequent section and are listed in numerical order.

## General

CEE 113 Solving Environmental Problems for Urban Regions (also ENGRI 113) (S,3cr.)

CEE 116 Modern Structures (also ENGRI 116) (F,3cr.)

CEE 241 Engineering Computation (also ENGRD 241) (S,3cr.)

CEE 304 Uncertainty Analysis in Engineering (F,4cr.)

CEE 308 Introduction to CADD (F,S,1cr.)

CEE 309 Special Topics in Civil and Environmental Engineering (F,S,var.)

CEE 323 Engineering Economics and Management (also ENGRG 323) (S,Su,3cr.)

CEE 400 Senior Honors Thesis (F,S,var.)

CEE 401 Undergraduate Engineering Teaching in CEE (F,S,var.)

## Civil Infrastructure

See also: CEE 116, CEE 241, CEE 304, CEE 308, CEE 503, and CEE 595

### *Geotechnical Engineering*

CEE 341 Introduction to Geotechnical Engineering and Analysis (S,4cr.)

CEE 440 Foundation Engineering (F,3cr.)

CEE 441 Retaining Structures and Slopes (S,3cr.)

CEE 444 Environmental Site and Remediation (S,3cr.)

CEE 501/502 Design Project in Geotech/Structures (F,S,3cr.)

CEE 602 Seminar—Civil Infrastructure (F,S,1cr.)

CEE 640 Foundation Engineering (F,3cr.)

CEE 641 Retaining Structures and Slopes (S,3cr.)

CEE 644 Environmental Applications of Geotechnical Engineering (S,3cr.)

CEE 649 Special Topics in Geotechnical Engineering (F,S,var.)

CEE 740 Engineering Behavior of Soils (F,3cr.)

CEE 741 Rock Engineering (F,3cr.)

CEE 744 Advanced Foundation Engineering (S,2cr.)

CEE 745 Soil Dynamics (S,3cr.)

CEE 746 Embankment Dam Engineering (S,2cr.)

CEE 749 Research in Geotechnical Engineering (F,S, var.)

CEE 840 Thesis—Geotechnical Engineering (F,S,var.)

***Structural Engineering***

CEE 116 Modern Structures (F,3cr.)

CEE 371 Structural Modeling and Behavior (S,4cr.)

CEE 372 Structural Mechanics and Analysis (F,4cr.)

CEE 471 Fundamentals of Structural Mechanics (F,3cr.)

CEE 472 Finite Element Analysis of Solids and Structures (S,3cr.)

CEE 473 Design of Concrete Structures (F,4cr.)

CEE 474 Design of Metal Structures (F,3cr.)

CEE 475 Introduction to Composite Materials (S,3cr.)

CEE 476 Evaluation and Failure of Structures (S,3cr.)

CEE 477 Concrete Materials and Construction (S,3cr.)

CEE 478 Structural Dynamics and Earthquake Engineering (S,3cr.)

CEE 479 Collaborative-Distance Design of Structural Systems (F,S,8cr.)

CEE 481 LRFD-Based Engineering of Wood Structures (S,3cr.)

CEE 501/502 Design Project in Structural Engineering (F,S,3cr.)

CEE 602 Seminar—Civil Infrastructure (F,S,1cr.)

CEE 671 Structural Mechanics (F,3cr.)

CEE 672 Finite Element Analysis of Solids and Structures (S,3cr.)

CEE 673 Design of Concrete Structures (F,4cr.)

CEE 675 Concrete Materials and Construction (S,3cr.)

CEE 676 Finite Element Analysis for Mechanical, Structural, and Aerospace Applications (S,3cr.)

CEE 677 Engineering Analysis (F,3cr.)

CEE 678 Structural Dynamics and Earthquake Engineering (S,3cr.)

CEE 679 Evaluation and Failure of Structures (S,3cr.)

CEE 697 Special Topics in Structural Engineering (F,S,var.)

CEE 770 Engineering Fracture Mechanics (F,3cr.)

CEE 771 Stochastic Mechanics (F,3cr.)

CEE 772 Random Vibration (F,3cr.)

CEE 773 Structural Reliability (F,3cr.)

CEE 774 Advanced Structural Concrete (F,3cr.)

CEE 775 Mathematical and Computational Modeling of Material Behavior (S,3cr.)

CEE 776 Advanced Topics in Stability (F,3cr.)

CEE 777 Computational Solids and Structural Mechanics (S,4cr.)

CEE 778 National Disaster Risk Assessment and Management (S,3cr.)

CEE 783 Civil and Environmental Engineering Materials Project (F,S,var.)

CEE 785 Research in Structural Engineering (F,S,var.)

CEE 880 Thesis—Structural Engineering (F,S,var.)

## Environment

See also CEE 113, CEE 241, and CEE 304

***Environmental Engineering***

CEE 113 Solving Environmental Problems for Urban Regions (S,3cr.)

CEE 351 Environmental Quality Engineering (S,3cr.)

CEE 451 Microbiology for Environmental Engineering (F,3cr.)

CEE 452 Water Supply Engineering (S,3cr.)

CEE 453 Laboratory Research in Environmental Engineering (S,3cr.)

CEE 454 Sustainable Small-Scale Water Supplies (F,3cr.)

CEE 501/502 Design Project in Environmental Engineering (F,S,3cr.)

CEE 601 Seminar—Water Resources and Environmental Engineering (F,1cr.)

CEE 653 Water Chemistry for Environmental Engineering (F,3cr.)

CEE 654 Aquatic Chemistry (S,3cr.)

CEE 655 Transport, Mixing, and Transformation in the Environment (F,3cr.)

CEE 656 Physical/Chemical Process (F,3cr.)

CEE 657 Biological Processes (S,3cr.)

CEE 658 Microbial Biodegradation and Biocatalysis Lab (S,3cr.)

CEE 659 Seminar—Environmental Quality Engineering (S,1cr.)

CEE 750 Research in Environmental Engineering (F,S,var.)

CEE 759 Special Topics in Environmental Engineering (F,S,var.)

CEE 850 Thesis—Environmental Engineering (F,S,var.)

***Environmental Systems***

See Engineering Systems and Management mission areas for a listing of courses in Environmental and Public Systems.

***Environmental Fluid Mechanics and Hydrology***

CEE 331 Fluid Mechanics (F,Su,4cr.)

CEE 332 Hydraulic Engineering (S,4cr.)

CEE 431 Introduction to Groundwater Hydrology (also GEOL 445 and BEE 471) (S,3cr.)

CEE 432 Hydrology (S,3cr.)

CEE 435 Coastal Engineering (S,3cr.)

CEE 436 Case Studies in Environmental Fluid Mechanics (S,4cr.)

CEE 437 Experimental Methods in Fluid Dynamics (S,3cr.)

CEE 501/502 Design Project in Fluid Mechanics and Hydrology (F,S,3cr.)

CEE 601 Seminar—Water Resources and Environmental Engineering (F,1cr.)

CEE 631 Computational Simulation of Transport in the Environment (S,3cr.)

CEE 632 Hydrology (S,3cr.)

CEE 633 Flow in Porous Media and Groundwater (F,3cr.)

CEE 634 Boundary Layer Meteorology (F,3cr.)

CEE 635 Small and Finite Amplitude Water Waves (S,3cr.)

CEE 636 Environmental Fluid Mechanics (S,3cr.)

CEE 637 Experimental Methods in Fluid Dynamics (S,4cr.)

CEE 638 Seminar—Hydraulics (S,1cr.)

CEE 639 Special Topics in Hydraulics (F,S,var.)

CEE 655 Transport, Mixing, and Transformation in the Environment (F,3cr.)

CEE 735 Research in Hydraulics (F,S,var.)

CEE 830 Thesis—Fluid Mechanics and Hydrology (F,S,var.)

## Engineering Systems and Management

See also CEE 113, CEE 241, and CEE 304

***Engineering Management***

CEE 490 Management Practice in Project Engineering (F,3cr.)

CEE 590 Project Management (F,S,4cr.)

CEE 591 Engineering Management Project (F,3cr.)

CEE 592 Engineering Management Project (S,3cr.)

CEE 593 Engineering Management Methods: Data, Information, and Modeling (F,3cr.)

CEE 594 Economic Methods for Engineering and Management (S,4cr.)

CEE 595 Construction Planning and Operations (F,3cr.)

CEE 596 Management Issues in Forensic Engineering (F,3cr.)

CEE 597 Risk Analysis and Management (S,3cr.)

CEE 598 Introduction to Decision Analysis (F,3cr.)

CEE 692 Special Topics in Engineering Management (F,S,var.)

CEE 694 Research in Engineering Management (F,S,var.)

***Environmental and Public Systems***

CEE 323 Engineering Economics and Management (also ENGRG 323) (S,Su,3cr.)

CEE 501/502 Design Project in Environmental Systems (F,S,3cr.)

CEE 597 Risk Analysis and Management (S,3cr.)

CEE 620 Water Resources Systems Engineering (S,3cr.)

CEE 621 Stochastic Hydrology (S,3cr.)

CEE 623 Environmental Quality Systems Engineering (F,3cr.)

CEE 628 Seminar—Environmental and Water Resources Systems Analysis (S,1cr.)

CEE 722 Environmental and Water Resources Systems Analysis Research (F,S,var.)

CEE 729 Special Topics in Environmental and Water Resources Systems Analysis (F,S,var.)

CEE 820 Thesis—Environmental and Water Resources Systems (F,S,var.)

***Remote Sensing***

CEE 411 Remote Sensing: Resource Inventory Methods (also CSS 411) (S,3cr.)

CEE 610 Remote Sensing Fundamentals (F,3cr.)

CEE 615 Digital Image Processing (S,3cr.)

CEE 617 Special Topics—Remote Sensing (F,S,var.)

CEE 710 Research—Remote Sensing (F,S,var.)

CEE 810 Thesis—Remote Sensing (F,S,var.)

***Systems Engineering***

CEE 406 Civil Infrastructure Systems (S,3cr.)

CEE 504 Applied Systems Engineering (also M&AE 591, ECE 512, OR&IE 512, SYSEN 510, COM S 504) (F,3cr.)

CEE 505 Applied Systems Engineering (also M&AE 592, ECE 513, OR&IE 513, SYSEN 520, COM S 505) (S,3cr.)

CEE 509 Heuristic Methods of Optimization (also COM S 574, CIS 572, OR&IE 533) (F,3–4cr.)

CEE 603 Seminar—Engineering Systems and Management (F,S,1cr.)

***Transportation***

CEE 361 Introduction to Transportation Engineering (S,Su,3cr.)

CEE 463 Transportation and Information Technology (F,3cr.)

CEE 464 Transportation Systems Design (S,3cr.)

CEE 661 Urban Transportation Planning and Modeling (F,3cr.)

CEE 662 Urban Transportation Network and Design (F,3cr.)

CEE 663 Network Flows and Algorithms (S,3cr.)

CEE 762 Practicum in Modeling Transportation Systems (F,3cr.)

CEE 764 Special Topics in Transportation (F,S,var.)

CEE 860 Thesis—Transportation Engineering (F,S,var.)

**CEE 113 Solving Environmental Problems for Urban Regions (also ENGRI 113)**

Spring. 3 credits. Students must register under ENGRI 113. M. L. Weber-Shirk.

This is a course in the Introduction to Engineering series. For description, see ENGRI 113.

**CEE 116 Modern Structures (also ENGRI 116)**

Fall. 3 credits. Students must register under ENGRI 116. M. J. Sansalone.

This is a course in the Introduction to Engineering series. For description, see ENGRI 116.

**CEE 241 Engineering Computation (also ENGRD 241)**

Spring. 3 credits. Prerequisites: COM S 100 and MATH 293. Corequisite: MATH 294 (completion of MATH 294 is suggested). Students must register under ENGRD 241. C. A. Shoemaker.

For description, see ENGRD 241.

**CEE 304 Uncertainty Analysis in Engineering**

Fall. 4 credits. CEE Engineering Co-op students may substitute summer ENGRD 270. Prerequisite: first-year calculus. J. R. Stedinger.

Introduction to probability theory and statistical techniques, with examples from civil, environmental, biological, and related disciplines. Course covers data presentation, commonly used probability distributions describing natural phenomona and material properties, parameter estimation, confidence intervals, hypothesis testing, simple linear regression, and nonparametric statistics. Examples include structural reliability, windspeed/flood distributions, pollutant concentrations, and models of vehicle arrivals.

**CEE 308 Introduction to CADD**

Fall, spring. 1 credit. Prerequisite: affiliation in CEE or permission of instructor. Course begins second full week of classes. J. F. Abel.

Learn to employ Computer Aided Design and Drafting (CADD) to construct 2D drawings and 3D models using a variety of AutoCAD 2004 techniques. Alternative software tools for 3D visualization and solid modeling are introduced. Course meets in ACCEL once per week for twelve weeks, and grades are based on attendance, weekly exercises completed in class, and a semester project.

**CEE 309 Special Topics in Civil and Environmental Engineering**

Fall, spring. 1–6 credits. Staff.

Supervised study by individuals or groups of upper-division students on an undergraduate research project or on specialized topics not covered in regular courses.

**CEE 323 Engineering Economics and Management (also ENGRG 323)**

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. D. P. Loucks.

For description, see ENGRG 323.

**CEE 331 Fluid Mechanics**

Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Prerequisite: ENGRD 202 (may be taken concurrently). W. H. Brutsaert.

Covers: hydrostatics, the basic equations of incompressible fluid flow, potential flow and dynamic pressure forces, viscous flow and shear forces, steady pipe flow, turbulence, dimensional analysis, laminar and turbulence boundary layer, flows around obstacles, and open-channel flow. Includes small-group laboratory assignments.

**CEE 332 Hydraulic Engineering**

Spring. 4 credits. Prerequisite: CEE 331. Offered alternate years. Not offered 2005–2006. M. L. Weber-Shirk.

Application of fluid-mechanical principles to problems of engineering practice and design: hydraulic machinery, open-channels, and river engineering. Lectures supplemented by laboratory work and a design project.

**CEE 341 Introduction to Geotechnical Engineering and Analysis**

Spring. 4 credits. Letter grade only. Prerequisites: ENGRD 202, CEE 331 (or equivalent), or permission of instructor. H. E. Stewart.

Fundamentals of geotechnical engineering. Topics covered include: origins and descriptions of soil and rock as engineering materials, subsurface exploration methods, principles of effective stresses, stress distribution and ground settlements from surface loads, steady-state and time-dependent subsurface fluid flow, soil strength and failure criteria, geoenvironmental applications, and introduction to hazardous waste containment systems.

**CEE 351 Environmental Quality Engineering**

Spring. 3 credits. L. W. Lion.

Introduction to engineering aspects of environmental quality control. Quality parameters, criteria, and standards for water and wastewater. Elementary analysis pertaining to the modeling of pollutant reactions in natural systems, and introduction to design of unit processes for wastewater treatment.

**CEE 361 Introduction to Transportation Engineering**

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. A. H. Meyburg and J. Mbwana.

Introduction to technological, economic, and social aspects of transportation. Emphasis is on design and functioning of transportation systems and their components. Covers: supply-demand interactions; system planning, design, and management; traffic flow, intersection control and network analysis; institutional and energy issues; and environmental impacts.

**CEE 371 Structural Modeling and Behavior**

Spring. 4 credits. Prerequisite: ENGRD 202. J. F. Abel.

An introduction to the structural engineering enterprise including aspects of design, loads, behavior, form, modeling, mechanics, materials, analysis, and construction/manufacturing. Case studies involve different scales and various materials. Topics include analytical and finite-element computational modeling of structural systems, including cables, arches, trusses, beams, frames, and 2D continua; deflections, strains, and stresses of structural members, systems, and 2D continua by analytical and work/energy methods, with a focus on linear elastic behavior; the foundations of matrix structural analysis; and the application of finite-element software.

**CEE 372 Structural Mechanics and Analysis**

Fall. 4 credits. Prerequisite: MATH 294, CEE 371. K. D. Papoulia.

Builds upon the prerequisites to create a strong foundation of mechanics and analysis for advanced courses in structural design, behavior, materials, or mechanics and in geotechnical, mechanical, or aerospace engineering. Intermediate topics in structural mechanics include shearing deformation in beams, effect of temperature changes and initial strains, complex loading on members, plane stress and strain, and modeling of linear and nonlinear material behavior.
The theory, formulation, and application of matrix analysis, particularly finite-element

displacement analysis, of structural systems such as trusses, frames, and continua, are covered. Special topics include symmetry in structural analysis, the force method in FEA and matrix analysis, and introductory material and geometric nonlinear analysis.

**CEE 400 Senior Honors Thesis**

Fall, spring. 1–6 credits. Staff.

Available to students admitted to the CEE Honors Program. Supervised research, study, and/or project work resulting in a written report or honors thesis.

**CEE 401 Undergraduate Engineering Teaching in CEE**

Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.

Methods of instruction developed through discussions with faculty and by assisting with the instruction of undergraduates under the supervision of faculty.

**CEE 406 Civil Infrastructure Systems**

Spring. 3 credits. Letter or S-U grade. Prerequisites: probability and statistics (CEE 304 or equivalent) and engineering economics (CEE 323 or equivalent). L. K. Nozick.

Introduction to the framing and solution of civil infrastructure problems using a systems engineering approach. Systems tools, such as optimization, life-cycle cost analysis, decision analysis, simulation, Markov modeling, and risk analysis are examined through case studies related to civil infrastructure.

**CEE 411 Remote Sensing: Resource Inventory Methods (also CSS 411)**

Spring. 3 credits. Prerequisite: permission of instructor. A. Lembo.

For description, see CSS 411.

**[CEE 431 Introduction to Groundwater Hydrology (also EAS 445 and BEE 471)**

Spring. 3 credits. Prerequisites: MATH 294 and ENGRD 202. Not offered 2004–2005. L. Cathles.

Intermediate-level study of aquifer geology, groundwater flow, and related design factors. Includes description and properties of natural aquifers, groundwater hydraulics, soil water, and solute transport.]

**CEE 432 Hydrology**

Spring. 3 credits. Prerequisite: CEE 331. Intended for undergraduates. Lectures concurrent with CEE 632. W. H. Brutsaert.

Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers. See description for CEE 632.

**[CEE 435 Coastal Engineering**

Spring. 4 credits. Prerequisite: CEE 331. Offered 2005–2006. P. L-F. Liu.

This course covers the following topics: review of hydrodynamics; small amplitude wave theory; wave statistics; wave-structure interactions; coastal processes.]

**[CEE 436 Case Studies in Environmental Fluid Mechanics**

Spring. 4 credits. Prerequisite: CEE 331 or equivalent. Not offered 2004–2005. E. A. Cowen.

An introduction to fundamental fluid mechanics and transport processes of the environment through laboratory- and field-based studies (Cayuga Lake, and Fall, Six-Mile, and Cascadilla Creeks) and case studies. Topics include surface and internal wave dynamics, sediment and nutrient/contaminant transport, and interfacial transfer. Lectures are based on laboratory/field projects. Course includes a design project.]

**[CEE 437 Experimental Methods in Fluid Dynamics**

Spring. 3 credits. Prerequisites: CEE 331 or equivalent and CEE 304 or equivalent (both may be taken concurrently). Next offered 2005–2006. E. A. Cowen.

Same as CEE 637 but no project is required. For description, see CEE 637.]

**CEE 440 Foundation Engineering**

Fall. 3 credits. Prerequisite: CEE 341. F. H. Kulhawy.

This course covers soil exploration, sampling, and in-situ testing techniques; bearing capacity, stress distribution, and settlement; design of shallow and deep foundations; compaction and site preparation; and seepage and dewatering of foundation excavations.

**CEE 441 Retaining Structures and Slopes**

Spring. 3 credits. Prerequisite: CEE 341. T. D. O'Rourke.

This course covers Earth pressure theories; design of rigid, flexible, braced, tied-back, slurry, and reinforced soil structures; stability of excavation, cut, and natural slopes; and design problems stressing application of course material under field conditions of engineering practice.

**CEE 444 Environmental Site and Remediation Engineering**

Spring. 3 credits. Prerequisite: CEE 341. T. D. O'Rourke.

This course covers the principles of hydrogeology, contaminant migration, and remediation technologies related to geotechnical and environmental engineering. Emphasis is on environmental site assessment, site feasibility studies, selection of remediation procedures, and engineered landfills. Design problems are based on real projects and involve visits from practicing engineers.

**CEE 451 Microbiology for Environmental Engineering**

Fall. 3 credits. Prerequisites: two semesters of college chemistry; organic chemistry or permission of instructor. R. E. Richardson.

This course is an introduction to the fundamental aspects of microbiology and biochemistry that are pertinent to environmental engineering and science. The course provides an overview of the characteristics of bacteria, Archaea, unicellular Eukaryotes (protozoa, algae, fungi), and viruses. Discussions of cell structure, bioenergetics and metabolism, and microbial genetics are included. Focus is then applied to topics pertinent to environmental engineering: pathogens; disease and immunity; environmental influences on microorganisms; roles of microbes in the carbon, nitrogen, and sulfur cycles; enzymes; molecular microbiology; and microbial ecology. This is an introductory course and is inappropriate for those who have taken BIOMI 290 or equivalent.

**CEE 452 Water Supply Engineering**

Spring. 3 credits. Prerequisites: CEE 351. J. J. Bisogni.

Analysis of contemporary threats to human health from water supplies. Criteria and standards for potable-water quality. Water-quality control theory. Design of water supply facilities.

**CEE 453 Laboratory Research in Environmental Engineering**

Fall. 3 credits. Prerequisites: CEE 351 or permission of instructor. M. L. Weber-Shirk.

Laboratory investigations of reactor flow characteristics; acid rain/lake chemistry; contaminated soil-site assessment and remediation; and wastewater treatment. Design of laboratory experiments, data analysis, computerized process control, and model development are emphasized.

**CEE 454 Sustainable Small-Scale Water Supplies**

Fall. 3 credits. Offered alternate years. M. L. Weber-Shirk.

This course covers the design and analysis of small-scale drinking water supply systems. We explore the technical, economic, and social constraints that form the sustainable space—i.e., the set of viable technologies that could be adopted progressively to improve the availability and quality of water. Students work in teams to design water supply and treatment systems.

**CEE 463 Transportation and Information Technology**

Fall. 3 credits. J. R. Mbwana.

Improving the use of existing facilities has become an important objective in transportation planning. This course examines the role of computer and telecommunications technologies to achieve these improvements. Specific attention is focused on the development of analyses to evaluate the benefits of inclusion of these technologies in transportation systems.

**CEE 464 Transportation Systems Design**

Spring. 3 credits. Prerequisite: CEE 361. M. A. Turnquist.

Advanced techniques for physical and operational design of transportation systems, including analytical modeling techniques underlying design criteria. Evaluation of alternative designs. Management and operating policies, including investment strategies. Facility location decisions, networks, and passenger and freight terminals.

**CEE 471 Fundamentals of Structural Mechanics**

Fall. 3 credits. Prerequisites: ENGRD 202, MATH 294. Primarily for seniors or by permission of the instructor. M. D. Grigoriu.

Course topics include beam bending; beams on elastic foundations; stability analysis for columns and beam-columns; linear elasticity; numerical solutions for linear elasticity problems; and applications including stress concentration, torsion, and plates.

**CEE 472 Finite Element Analysis of Solids and Structures**

Spring. 3 credits. Prerequisites: CEE 371, CEE 372, and CEE 471. W. Aquino.

This course covers the formulation of the finite element method in 2D and 3D continuum, basic 2D and 3D continuum isoparametric elements, plate and shell elements, modeling and programming aspects of the finite element method, and static and transient problems. A large part of the course is devoted to understanding element formulations, testing elements (patch test), and addressing problems such as shear and volumetric locking, among others. Emphasis is placed on understanding fundamental aspects of the method for making intelligent use of commercial software and obtaining a strong background for moving to further study and research. Problems are drawn primarily from structural and solid mechanics.

**CEE 473 Design of Concrete Structures**
Fall. 4 credits. Prerequisite: CEE 341 or permission of instructor. K. C. Hover.
Behavior and design of reinforced concrete and structures. Discussion of how forces are transferred through elements of building systems. Includes a semester project requiring the design of a reinforced concrete structure.

**CEE 474 Design of Metal Structures**
Fall. 4 credits. Prerequisite: CEE 341 or permission of instructor. T. Pekoz.
Behavior and design of steel members, connections, and structures. Discussion of structural systems for buildings and bridges.

**CEE 475 Introduction to Composite Materials (also M&AE 455, MS&E 555, and T&AM 455)**
Spring. 3 credits. L. Phoenix.
For description, see T&AM 455.

**[CEE 476 Evaluation and Failure of Structures**
Spring. 3 credits. Offered alternate years. Prerequisites: ENGRD 202, ENGRD 261, and ENGRD 203; CEE 371 and CEE 473. Not offered 2004–2005. M. J. Sansalone.
This course teaches material and structural evaluation through the lens of failure. The course builds upon and integrates what students have learned in courses in physics, mechanics, dynamics, materials science, structural modeling/analysis, and design. In addition, the course teaches the physics of methods used for condition assessment of structures (e.g., stress wave propagation, electromagnetic wave propagation, heat flow), introduces students to structural damage and assessment of damage caused by earthquake/wind loads on structures, and introduces students to blast/impact loadings on structures and the concept of progressive collapse.]

**CEE 477 Concrete Materials and Construction**
Spring. 3 credits. K. C. Hover.
This course covers the materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. Topics include cement chemistry and physics, mix design, admixtures, engineering properties, testing of fresh and hardened concrete, and the effects of construction techniques on material behavior.

**CEE 478 Structural Dynamics and Earthquake Engineering**
Spring. 3 credits. M. D. Grigoriu.
Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

**[CEE 479 Collaborative, Distance Design of Structural Systems (also M&AE 491)**
Fall, spring. 8 credit hours. Students who enroll in CEE 479 are expected to take it in both the fall and spring semesters. Not offered 2004–2005. A. Ingraffea, S. Jones.
This is a new senior-level design course, funded by NASA and the state of New York and taught jointly with Syracuse University. It emphasizes teamwork, collaboration at a distance, and multidisciplinary activities. The project is based on structural systems for a reusable launch vehicle. The course involves design, analysis, simulation, building, testing, virtual reality, and synchronous and asynchronous learning environments. First semester covers conceptual design, study of advanced mechanics, materials, software applications, risk and cost analysis. The second semester involves detailed design, construction, testing, and simulation.]

**CEE 481 LRFD-Based Engineering of Wood Structures (also BEE 481)**
Spring. 3 credits. Prerequisite: ENGRD 202.
For description see BEE 481 in the College of Agriculture and Life Sciences section of this catalog.

**[CEE 490 Management Practice in Project Engineering**
Fall. 3 credits. Prerequisite: permission of instructor. Next offered 2007–2008. K. C. Hover.
An introduction to the principles of project management. Planning, organizing, communicating, scheduling, and controlling of engineering work done in project teams.]

**CEE 492 Engineers for a Sustainable World: Engineering in International Development**
Fall. 3 credits. R. A. Davidson and P. Doing.
Engineering-based group service projects offer real-life engineering research and design experience, from problem formulation through implementation. They may be international or local, and may relate to any kind of engineering. Students work on interdisciplinary teams with a project supervisor and a partner community organization. Course readings and a writing assignment cover the relationship between engineering and international development, the philosophy and politics of technology, and ethics in engineering practice.

**CEE 501/502 Design Project**
Fall, spring. 3 credits each term. Required for students in the M.Eng. (Civil) program. Staff.
CEE design projects present students with an exemplary design experience that reflects those carried out in the course of professional practice. Projects are typically performed by student design groups, and the topics reflect the diverse specialty areas of the Civil and Environmental engineering field as described below.

**CEE 501/502 Design Project in Structural Engineering**
Design of a major civil engineering project. Planning and a preliminary design are completed during the fall term; the final design is completed in the January intersession.

**CEE 501/502 Design Project in Geotechnical Engineering**
Design of major geotechnical engineering project. Planning and preliminary design during the fall term; final design completed in January intersession.

**CEE 501/502 Design Project in Environmental Water Systems**
Design of a major water systems project.

**CEE 501/502 Design Project in Environmental Engineering**
Design of a major environmental engineering project.

**CEE 501/502 Design Project in Environmental Fluid Mechanics and Water Research**
Design of a major environmental systems fluid mechanics and water research project.

**CEE 503 Professional Practice and Ethics in Engineering**
Spring. 3 credits. Open to all engineering undergraduate seniors and graduate students; required for students in the M.Eng. (Civil) program. C. H. Trautmann.
This course is designed to prepare students for professional practice by examining various nontechnical aspects of engineering, including finance, marketing, ethics, law, and management.

**CEE 504 Applied Systems Engineering (also COM S 504, ECE 512, M&AE 591, OR&IE 512, SYSEN 510)**
Fall. 3 credits. Prerequisite: senior or graduate standing in an engineering field; concurrent or recent (in the past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. A. R. George and R. Roundy.
For description, see SYSEN 510.

**CEE 505 Applied Systems Engineering (also COM S 505, ECE 513, M&AE 592, OR&IE 513, SYSEN 520)**
Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512 or SYSEN 520). Staff.
For description, see SYSEN 520.

**CEE 509 Heuristic Methods for Optimization (also COM S 572, CIS 572, OR&IE 533)**
Fall. 3 or 4 credits. Prerequisites: graduate standing or COM S, ENGRD 211, ENGRD 321, or CEE 241; ENGRD 241 or permission of instructor. C. A. Shoemaker and B. Selman.
This course teaches heuristic search methods including simulated annealing, tabu search, genetic algorithms, derandomized evolution strategy, and random walk developed for optimization of combinatorial- and continuous-variable problems. Application project options include wireless networks, protein folding, job shop scheduling, partial differential equations, satisfiability, or independent projects. Statistical methods are presented for comparing algorithm results. Advantages and disadvantages of heuristic search methods for both serial and parallel computation are discussed in comparison with other optimization algorithms.

**CEE 590 Project Management**
Fall, spring. 4 credits. Prerequisite: permission of instructor. F. J. Wayno.
A core graduate course in project management for people who will manage technical or engineering projects. Focuses both on the "technical" tools of project management (methods for planning, scheduling, and control) and the "human" side (forming a project team, managing performance, resolving conflicts, etc.), with somewhat greater emphasis on the latter.

**CEE 591 Engineering Management Project**
Fall. 3 credits. Prerequisite: permission of instructor. P. Carr.
An intensive evaluation of the management aspects of a major engineering project or system. Most students work on a large group project in the area of project management, but students may also work singly or in small groups on an engineering management topic of special interest to them.

**CEE 592 Engineering Management Project**
Spring. 3 credits. Prerequisite: permission of instructor. P. Carr.
A continuation of CEE 591.

**CEE 593 Engineering Management Methods: Data, Information, and Modeling**
Fall. 3 credits. Prerequisites: CEE 323 and CEE 304 or equivalent. M. A. Turnquist.
Methods for managing data and transforming data into information. Modeling as a means to synthesize information into knowledge that can form the basis for decisions and actions. Application of statistical methods and optimization to managerial problems in project design, scheduling, operations, forecasting, and resource allocation.

**CEE 594 Economic Methods for Engineering and Management (also ECON 494)**
Spring. 4 credits. Prerequisite: calculus, probability and statistics, and a course in economics. For seniors and graduate students or by permission of instructor. R. E. Schuler.
Economic concepts are introduced and used to select, calibrate and apply proper analytic decision tools in engineering design and management. Topics covered include: market analysis and pricing strategies; production choices and cost estimation; input acquisition and employee motivation; project evaluation and the cost of capital; decision-making in risky and uncertain environments; industry structure, bidding strategies and game theory; plus the regulatory and ethical consequences of overall managerial strategies.

**CEE 595 Construction Planning and Operations**
Fall. 3 credits. K. C. Hover.
A course on the fundamentals of construction planning: organization of the work site; construction planning, scheduling, and cost estimating; bidding; temporary structures; contract documents and the relationships among owners, designers, contractors, suppliers, and developers.

**CEE 596 Management Issues in Forensic Engineering**
Fall. 3 credits. P. G. Carr.
This course is an introduction to forensic engineering, contract administration, and dispute resolution, with particular emphasis on contract formation, performance, breach, and remedies. Through case studies in forensics, the engineer's standard of care and design obligations are explored. The engineer's technical and ethical duties to the client, the contractors, and the public are examined.

**CEE 597 Risk Analysis and Management**
Spring. 3 credits. Prerequisite: An introduction to probability and statistics course such as: CEE 304, ENGRD 270, ILSRT 210, BTRY 261 or AEM 210; and two semesters of calculus. For seniors and graduate students or by permission of instructor. J. R. Stedinger.
Course develops a working knowledge of risk terminology and reliability engineering, analytic tools and models used to analyze environmental and technological risks, and social and psychological risk issues. Discussions address life risks in the United States historical accidents, natural hazards, transportation risks, industrial accidents, waste incineration, air pollution modeling, public health, regulatory policy, risk communication, and risk management.

**CEE 598 Introduction to Decision Analysis**
Fall. 3 credits. Prerequisite: an introduction to probability and statistics course such as CEE 304, ENGRD 270, ILRST 210, BTRY 261 or AEM 210. For seniors and graduate students or by permission of instructor. R. A. Davidson.
Framework to structure the way we think about decision situations that are complicated by uncertainty, complexity, and competing objectives. Specific decision analysis concepts and tools, such as decision trees, sensitivity analysis, value of information, and utility theory. Applications to all areas of engineering and life. Includes a group project to analyze a real-world decision.

**CEE 601 Seminar—Water Resources and Environmental Engineering**
Fall. 1 credit. R. E. Richardson.
Presentation of topics of current interest.

**CEE 602 Seminar—Civil Infrastructure**
Fall, spring. 1 credit. Required for first-year graduate students. Staff.
Presentation of topics of current interest.

**CEE 603 Seminar—Engineering Systems and Management**
Fall, spring. 1 credit. Staff.
Presentation of topics of current interest.

**CEE 605 Seminar—Issues in Risk Analysis**
Fall. 1 credit. S-U option. Staff.
Discussion of current issues and ongoing research on risk analysis issues from many perspectives with an emphasis on environmental risk analysis. Speakers address problem formulation, quantitative/qualitative methods in assessment of risk, communication issues, and challenges to risk assessment methodologies. Some sessions held jointly with other seminar series. Enrollment in seminar requires short reports and participation in three required discussion meetings for class members designed to integrate the issues raised during the semester.

**CEE 606 Civil Infrastructure Systems**
Spring. 3 credits. Letter or S-U grades. Prerequisites: probability and statistics (CEE 304 or equivalent) and engineering economics (CEE 323 or equivalent). L. K. Nozick.
This course is an introduction to the framing and solution of civil infrastructure problems using a systems engineering approach. Systems tools, such as optimization, life-cycle cost analysis, decision analysis, simulation, Markov modeling, and risk analysis, are examined through case studies related to civil infrastructure.

**CEE 610 Remote Sensing Fundamentals (also CSS 660)**
Fall. 3 credits. Prerequisite: permission of instructor. W. D. Philpot.
An introduction to equipment and methods used in obtaining information about earth resources and the environment from aircraft or satellite. Coverage includes sensors, sensor and ground-data acquisition, data analysis and interpretation, and project design.

**CEE 615 Digital Image Processing**
Spring. 3 credits. Prerequisite: facility with algebra, trigonometry, and basic statistics or permission of instructor. W. D. Philpot.
An introduction to digital image-processing concepts and techniques, with emphasis on remote-sensing applications. Topics include image acquisition, enhancement procedures, spatial and spectral feature extraction, and classification, with an introduction to hyperspectral data analysis. Assignments require the use of image-processing software and graphics.

**CEE 617 Special Topics—Remote Sensing**
On demand. 1–6 credits. W. D. Philpot.
Students may elect to undertake a project in remote sensing. The work is supervised by a professor in this subject area.

**CEE 620 Water-Resources Systems Engineering**
Spring. 3 credits. Prerequisites: CEE 323 and CEE 593 or BEE 475. D. P. Loucks.
Development and application of deterministic and stochastic optimization and simulation models for water-resources planning and management. Covers river-basin modeling, including reservoir design and operation, irrigation planning and operation, hydropower-capacity development, flow augmentation, flood control and protection, and water-quality prediction and control.

**[CEE 621 Stochastic Hydrology**
Spring. 3 credits. Prerequisites: CEE 304 or permission of instructor. Not offered 2004–2005. J. R. Stedinger.
Course examines statistical, time series, and stochastic optimization methods used to address water resources planning and management problems involving uncertainty objectives and hydrologic inputs. Statistical issues include: maximum likelihood and moments estimators; censored data sets and historical information; probability plotting; Bayesian inference; regionalization methods; ARMA models; multivariate stochastic streamflow models; stochastic simulation; and stochastic reservoir-operation optimization models.]

**[CEE 623 Environmental Quality Systems Engineering**
Fall. 3 credits. Prerequisites: MATH 294, optimization, and graduate standing or permission of instructor. Not offered 2004–2005. C. A. Shoemaker.
Applications of optimization, simulation methods, and uncertainty analysis to the prevention and remediation of pollution. Case studies include: regional waste and wastewater treatment, restoration of dissolved oxygen levels in rivers, and reclamation of contaminated groundwater. Applications use linear programming, integer, dynamic, nonlinear programming, and sensitivity analysis.]

**[CEE 626 Case Studies in Environmental Fluid Mechanics**
Spring. 4 credits. Prerequisite: CEE 331 or equivalent. Not offered 2004–2005. E. A. Cowen.
An introduction to fundamental fluid mechanics and transport processes of the environment through laboratory- and field-based studies (Cayuga Lake and Fall, Six-Mile, and Cascadilla Creeks) and case studies. Topics include surface and internal wave dynamics, sediment and nutrient/contaminant transport, and interfacial transfer. Lectures are based on laboratory/field projects. Course includes a design project.]

**CEE 628 Seminar—Environmental and Water Resources Systems Analysis**
Spring. 1 credit. Prerequisite: permission of instructor. C. A. Shoemaker.
Graduate students and faculty members give informal lectures on various topics related to ongoing research in environmental or water resources systems planning and analysis.

**CEE 631 Computational Simulation of Flow and Transport in the Environment**
Spring. 3 credits. Prerequisites: MATH 294 or equivalent, ENGRD 241 or experience in numerical methods and programming, and elementary fluid mechanics. Not offered 2005–2006. P. L.-F. Liu.
This course covers fundamental equations of saturated and unsaturated flow in porous media; flow in fractured media; numerical modeling of transport in porous media; diffusion and advective diffusion in one, two, and three dimensions; anisotropy; and additional terms for reactive substances. The course teaches various numerical methods including finite difference, finite elements, and boundary elements.

**CEE 632 Hydrology**
Spring. 3 credits. Prerequisite: CEE 331. W. H. Brutsaert.
Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers and scientists. Covers: physical and statistical prediction methods for design related to hydrologic processes; hydrometeorology and evaporation; infiltration and base flow; surface runoff and channel routing; linear and nonlinear hydrologic systems; and storage routing and unit hydrograph methods.

**[CEE 633 Flow in Porous Media and Groundwater**
Fall. 3 credits. Prerequisite: CEE 331. Not offered 2004–2005. W. H. Brutsaert.
Fluid mechanics and equations of single-phase and multiphase flow; methods of solution. Applications involve aquifer hydraulics, pumping wells; drought flows; infiltration, groundwater recharge; land subsidence; seawater intrusion, miscible displacement; and transient seepage in unsaturated materials.]

**[CEE 634 Boundary Layer Meteorology**
Fall. 3 credits. Prerequisite: CEE 331 or permission of instructor. Not offered 2004–2005. W. H. Brutsaert.
Physical processes in the lower atmospheric environment: turbulent transport in the atmospheric boundary layer, surface-air interaction, disturbed boundary layers, radiation. Applications include sensible and latent heat transfer from lakes, plant canopy flow and evapotranspiration, turbulent diffusion from chimneys and cooling towers, and related design issues.]

**[CEE 635 Small and Finite Amplitude Water Waves**
Spring. 3 credits. Next offered 2005–2006. P. L.-F. Liu.
Review of linear and nonlinear theories of ocean waves. Discussions on the applicability of different wave theories to engineering problems.]

**[CEE 636 Environmental Fluid Mechanics**
Spring. 3 credits. Not offered 2004–2005. E. A. Cowen.
Course covers: analytic and modeling perspectives of environmental flows; mechanics of layered and continuously stratified fluids: internal waves, density currents, baroclinic motions, and turbulence; jets and plumes and their behavior in the environment; turbulent diffusion, shear flow dispersion, and wave-induced mixing processes; and applications to mixing processes in rivers, lakes, estuaries, and the coastal ocean.]

**[CEE 637 Experimental Methods in Fluid Dynamics (also M&AE 627)**
Spring. 4 credits. Prerequisites: CEE 331 or equivalent and CEE 304 or equivalent (both may be taken concurrently). Not offered 2004–2005. E. A. Cowen.
Introduction to experimental data collection and analysis, in particular as they pertain to fluid flows. Covers: computer-based experimental control, analog and digital data acquisition, discrete sampling theory, digital signal processing, uncertainty analysis. Also covers: analog transducers, acoustic and laser Doppler velocimetry, full-field (2-D) quantitative imaging techniques. Includes laboratory experiments and a project.]

**CEE 638 Seminar—Hydraulics**
Spring. 1 credit. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Staff.
Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

**CEE 639 Special Topics in Hydraulics**
On demand. 1–6 credits. Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

**CEE 640 Foundation Engineering**
Fall. 3 credits. Prerequisite: CEE 341. F. H. Kulhawy.
This course covers soil exploration, sampling, and in-situ testing techniques; bearing capacity, stress distribution, and settlement; design of shallow and deep foundations; compaction and site preparation; and seepage and dewatering of foundation excavations.

**CEE 641 Retaining Structures and Slopes**
Spring. 3 credits. Prerequisite: CEE 341. T. D. O'Rourke.
Course covers: Earth pressure theories; design of rigid, flexible, braced, tied-back, slurry, and reinforced soil structures; stability of excavation, cut, and natural slopes; and design problems stressing application of course material under field conditions of engineering practice.

**CEE 644 Environmental Site and Remediation Engineering**
Spring. 3 credits. Prerequisite: CEE 341 or equivalent or permission of instructor. T. D. O'Rourke.
Covers principles of hydrogeology, contaminant migration, and remediation technologies related to geotechnical and environmental engineering. Emphasis is on environmental site assessment, site feasibility studies, selection of remediation procedures, and engineered landfills. Design problems are based on real projects and involve visits from practicing engineers.

**CEE 649 Special Topics in Geotechnical Engineering**
On demand. 1–6 credits. Staff.
Supervised study of special topics not covered in the formal courses.

**CEE 653 Water Chemistry for Environmental Engineering**
Fall. 3 credits. Prerequisite: 1 semester of college chemistry or permission of instructor. L. W. Lion.
Principles of chemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters. Topics include chemical thermodynamics, reaction kinetics, acid-base equilibria, mineral precipitation/dissolution, and electrochemistry. The focus of the course is on the mathematical description of chemical reactions relevant to engineered processes and natural systems, and the numerical or graphical solution of these problems.

**[CEE 654 Aquatic Chemistry**
Spring. 3 credits. Prerequisite: CEE 653 or CHEM 287–288. Not offered 2004–2005. J. J. Bisogni.
Concepts of chemical equilibria applied to natural aquatic systems. Topics include acid-base reactions, buffer systems, mineral precipitation, coordination and redox reactions, Eh-pH diagrams adsorption phenomena, humic acid chemistry, and chemical-equilibria computational techniques. In-depth coverage of topics covered in CEE 653.]

**CEE 655 Transport, Mixing, and Transformation in the Environment**
Fall. 3 credits. Prerequisite: CEE 331. P. L.-F. Liu.
Application of fluid mechanics to problems of transport, mixing, and transformation in the water environment. Introduction to advective, diffuse, and dispersive processes in the environment. Boundary interactions: air-water and sediment-water processes. Introduction to chemical and biochemical transformation processes. Applications to transport, mixing, and transformation in rivers, lakes, and coastal waters.

**CEE 656 Physical/Chemical Process**
Fall. 3 credits. Prerequisite: previous or concurrent enrollment in CEE 653 or permission of instructor. J. J. Bisogni.
Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in the environment. Analysis and design of treatment processes and systems.

**CEE 657 Biological Processes**
Spring. 3 credits. Prerequisites: an introductory course in microbiology and CEE 656, or permission of instructor. J. M. Gossett.
Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in the environment. Bioenergetics analysis, stoichiometry, biokinetic, and design of biological treatment process.

**CEE 658 Microbial Biodegradation and Biocatalysis Lab**

Spring. 3 credits. Prerequisites: CEE 451 or BIOMI 290 or equivalent; CEE 351 or CHEME 390 or permission of instructor. R. E. Richardson.

Students explore the use of microbes in biodegradation and biocatalysis as well as the molecular techniques (i.e., analysis of DNA, RNA, and proteins) commonly used in these applications. Lectures cover enzyme classes and kinetics, selective isolation of organisms with desired bioconversion capabilities, effects of environmental parameters and cell-to-cell communication on gene expression, methods in microbial molecular biology, and contemporary case studies in biodegradation and biocatalysis. Laboratory sessions give students hands-on experience in molecular and analytical methods. Student teams design and then construct a bioreactor employing their own environmental isolates that degrade a selected contaminant or produce a desired compound.

**CEE 659 Seminar—Environmental Quality Engineering**

Spring. 1 credit. Prerequisite: enrollment as graduate student in environmental engineering. Staff.

Presentation and discussion of current research in environmental engineering.

**[CEE 661 Urban Transportation Planning and Modeling**

Fall. 3 credits. Prerequisite: CEE 361 or permission of instructor. Offered alternate years. Next offered 2005–2006. A. H. Meyburg.

This course covers modern transportation planning practice and the analytical tools that are necessary to engage in this field. Emphasis is on passenger transportation in the urban context. The legislative, political, and economic contexts of urban transportation planning (UTP) are discussed. The course presents the travel demand estimation process and the associated models and approaches and provides insights in travel survey data acquisition.]

**CEE 662 Urban Transportation Network Design and Analysis**

Fall. 3 credits. Prerequisite: CEE 361 or permission of instructor. L. K. Nozick.

This course covers the development and use of mathematical models for the design and analysis of urban transportation networks, including formulations and solution procedures based on user equilibrium and stochastic user equilibrium. Students apply these tools to a substantive real-world case study.

**[CEE 663 Network Flows and Algorithms**

Spring. 3 credits. Prerequisite: CEE 662 or permission of instructor. Offered alternate years. Not offered 2004–2005. M. A. Turnquist.

Algorithms for network flow problems encountered in transportation systems modeling, including shortest path, multi-objective shortest path, minimum cost flows, multi-commodity flows and generalized flows, are presented. Applications to vehicle routing, dynamic vehicle allocation, and network design are included.]

**CEE 671 Fundamentals of Structural Mechanics**

Fall. 3 credits. Prerequisites: ENGRD 202, MATH 294. Primarily for seniors or by permission of instructor. M. D. Grigoriu.

Course topics include beam bending, beams on elastic foundation, stability analysis for columns and beam-columns, linear elasticity, numerical solutions for linear elasticity problems, and applications including stress concentration, torsion, and plates.

**CEE 672 Finite Element Analysis of Solids and Structures**

Spring. 3 credits. Prerequisites: CEE 371, CEE 372, and CEE 471. W. Aquino.

This course covers the formulation of the finite element method in 2D and 3D continuum, basic 2D and 3D continuum isoparametric elements, plate and shell elements, modeling and programming aspects of the finite element method, and static and transient problems. A large part of the course is devoted to understanding element formulations, testing elements (patch test), and addressing problems such as shear and volumetric locking, among others. Emphasis is placed on understanding fundamental aspects of the method for making intelligent use of commercial software and obtaining a strong background for moving to further study and research. Problems are drawn primarily from structural and solid mechanics.

**CEE 673 Design of Concrete Structures**

Fall. 4 credits. Prerequisite: CEE 341 or permission of instructor. K. C. Hover.

This course covers the behavior and design of reinforced concrete and structures. Discussion of how forces are transferred through elements of building system is included. A semester project is assigned requiring the design of a reinforced concrete structure.

**CEE 674 Design of Metal Structures**

Fall. 4 credits. Prerequisite: CEE 341 or permission of instructor. T. Pekoz.

This course covers the behavior and design of steel members, connections, and structures. Discussion of structural systems for buildings and bridges is included.

**CEE 675 Concrete Materials and Construction**

Spring. 3 credits. K. C. Hover.

This course covers the materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. Topics include cement chemistry and physics, mix design, admixtures, engineering properties, testing of fresh and hardened concrete, and the effects of construction techniques on material behavior.

**CEE 676 Finite Element Analysis (also T&AM 666 and M&AE 680)**

Spring. 3 credits. Staff.

This course covers the conceptual, theoretical, and practical basis for finite element analyses in engineering, with emphasis on structural, mechanical, and thermal problems. It focuses on the FEM as a method for numerically solving partial differential equations. Topics include strong and weak problem forms; weighted-residual and variational formulations; formulations for elliptic, parabolic, and hyperbolic problems (Laplace's equation, elasticity, heat conduction, structural dynamics, wave propagation); meshing and error estimation and various kinds of elements.

**[CEE 677 Engineering Analysis**

Fall. 3 credits. Prerequisite: instructor permission. Not offered 2004–2005. M. D. Grigoriu.

Vector spaces, linear transformations, and eigenvalue problems with applications to matrix structural analysis, linear dynamics, stability, and principal stresses, strains, and moments of inertia. Fourier analysis for periodic and non-periodic functions, with applications to the solution of ordinary differential equations, beams, plates, and other structural mechanics problems. Partial differential equations with applications to the analysis of static and dynamic response of continuous systems and transport problems.]

**CEE 678 Structural Dynamics and Earthquake Engineering**

Spring. 3 credits. M. D. Grigoriu.

Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

**[CEE 679 Evaluation and Failure of Structures**

Spring. 3 credits. Offered alternate years. Not offered 2004–2005. M. J. Sansalone.

This course teaches material and structural evaluation through the lens of failure. The course builds upon and integrates what students have learned in courses in physics, mechanics, dynamics, materials science, structural modeling/analysis, and design. In addition, the course teaches the physics of methods used for condition assessment of structures (e.g., stress wave propagation, electromagnetic wave propagation, heat flow), introduces students to structural damage and assessment of damage caused by earthquake/wind loads on structures, and introduces students to blast/impact loadings on structures and the concept of progressive collapse.]

**CEE 692 Special Topics in Engineering Management**

On demand. 1–6 credits. Staff.

Individually supervised study of one or more specialized topics not covered in regular courses.

**CEE 694 Research in Engineering Management**

On demand. 1–6 credits. Staff.

The student may select an area of investigation in engineering management. Results should be submitted to the instructor in charge in the form of a research report.

**CEE 697 Special Topics in Structural Engineering**

On demand. 1–6 credits. Staff.

Individually supervised study or independent design or research in specialized topics not covered in regular courses. Occasional offering of such special courses as Shell Theory and Design, and Advanced Topics in Finite Element Analysis.

**CEE 710 Research—Remote Sensing**

On demand. 1–6 credits. W. D. Philpot.

For students who want to study one particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design procedures.

**CEE 722 Environmental and Water Resources Systems Analysis Research**

On demand. 1–6 credits. Prerequisite: permission of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.

Investigations of particular environmental or water resources systems problems.

**CEE 729 Special Topics in Environmental or Water Resources Systems Analysis**

On demand. 1–6 credits. Staff.

Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

**CEE 735 Research in Hydraulics**

On demand. 1–6 credits. Staff.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either experimental or theoretical in nature. Results should be submitted to the instructor in charge in the form of a research report.

**CEE 740 Engineering Behavior of Soils**

Fall. 3 credits. Prerequisite: CEE 341. H. E. Stewart.

Detailed study of the physiochemical nature of soil. Stress states due to geostatic loading and stress-history effects. In-depth evaluation of stress-strain-strength, compressibility, and hydraulic conductivity of natural soils.

**CEE 741 Rock Engineering**

Fall. 3 credits. Prerequisite: CEE 341 or permission of instructor. Recommended: introductory geology. T. D. O'Rourke.

Geological and engineering classifications of intact rock, discontinuities, and rock masses. Includes laboratory and field evaluation of properties. Covers: stress states and stress analysis; design of foundations on, and openings in, rock masses; and analysis of the stability of rock slopes.

**CEE 744 Advanced Foundation Engineering**

Spring. 2 credits. Prerequisite: CEE 640. F. H. Kulhawy.

A continuation of CEE 640, with detailed emphasis on special topics in soil-structure interaction. Typical topics include lateral and pullout loading of deep foundations, pile group behavior, foundations for offshore structures, foundations for special structures.

**[CEE 745 Soil Dynamics**

Spring. 3 credits. Prerequisite: permission of instructor. Next offered spring 2006. H. E. Stewart.

Study of soil behavior under dynamic loading conditions. Foundation design for vibratory loadings. Introductory earthquake engineering including field and laboratory techniques for determining dynamic soil properties and liquefaction potential. Covers design of embankments and retaining structures under dynamic loading conditions.]

**[CEE 746 Embankment Dam Engineering**

Spring. 2 credits. Prerequisites: CEE 641 and 741, or permission of instructor. Not offered 2004–2005. F. H. Kulhawy.

Principles of analysis and design for earth and rockfill dams. Materials, construction methods, internal and external stability, seepage and drainage, performance monitoring, abutment and foundation evaluation. Introduction to tailings dams.]

**CEE 749 Research in Geotechnical Engineering**

On demand. 1–6 credits. Staff.

For students who want to pursue a particular geotechnical topic in considerable depth.

**CEE 750 Research in Environmental Engineering**

On demand. 1–6 credits. Staff.

For students who want to study a particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design and analysis procedures.

**CEE 759 Special Topics in Environmental Engineering**

On demand. 1–6 credits. Staff.

Supervised study in special topics not covered in formal courses.

**CEE 762 Practicum in Modeling Transportation Systems**

Fall. 3 credits. Prerequisites: CEE 661, CEE 662, and CEE 663. Offered alternate years. L. K. Nozick.

Students develop appropriate models and practical solution procedures for decision making in transportation systems. Alternative approaches are compared by assessing the strengths and weakness of each. Case studies and model implementation skills are included.

**CEE 764 Special Topics in Transportation**

On demand. 1–6 credits. Staff.

Advanced subject matter not covered in depth in other regular courses.

**[CEE 770 Engineering Fracture Mechanics**

Fall. 3 credits. Prerequisite: CEE 672 or CEE 772 (M&AE 680/T&AM 666) and T&AM 753, or permission of instructor. Offered alternate years. Next offered 2005–2006. A. Ingraffea.

Computational and physical modeling of crack growth processes. Finite and boundary element-based simulation of brittle fracture initiation and propagation, fatigue crack growth, and elasto-plastic and cohesive approaches to inelastic crack growth. Element formulation, meshing and remeshing, interactive steering. Case studies across scales from geomechanics to micromechanics, and including metals, ceramics, and polymers. Laboratory techniques for fracture toughness, crack growth rate, and trajectory testing.]

**[CEE 771 Stochastic Mechanics in Science and Engineering**

Fall. 3 credits. Prerequisites: permission of instructor. Not offered 2004–2005. M. D. Grigoriu.

Review of probability theory, stochastic processes, and Ito formula with illustrations by Monte Carlo Simulation. Analytical and numerical methods for solving stochastic problems defined by algebraic, differential, and integral equations with random/deterministic coefficients and random/deterministic input. Applications include: solution of Laplace, transport, Schrodinger, and other deterministic partial differential equations; dynamic systems subjected to Gaussian and non-Gaussian noise; random eigenvalue problems; and homogenization, structure evolution, and pattern formation for random heterogeneous materials.]

**[CEE 772 Random Vibration**

Fall. 3 credits. Prerequisites: M&AE 326 and OR&IE 260, or equivalent, and permission of instructor. Not offered 2004–2005. M. D. Grigoriu.

Review of random-process theory, simulation, and first-passage time. Linear random vibration: second-moment response descriptors and applications from fatigue; seismic analysis; and response to wind, wave, and other non-Gaussian load processes. Nonlinear random vibration: equivalent linearization, perturbation techniques, Fokker-Planck and Kolomogorov equations, Itô calculus, and applications from chaotic vibration, fatigue, seismic analysis, and parametrically excited systems.]

**[CEE 773 Structural Reliability**

Fall. 3 credits. Prerequisite: permission of instructor. Offered alternate years. Not offered 2004–2005. M. D. Grigoriu.

Review of probability theory, practical measures for structural reliability, second-moment reliability indices, probability models for strength and loads, probability-based design codes, reliability of structural systems, imperfection-sensitive structures, fatigue, stochastic finite-element techniques, and elementary concepts of probabilistic fracture mechanics.]

**CEE 774 Advanced Structural Concrete**

Fall. 3 credits. W. Aquino.

The fundamental aspects of the mechanical behavior of concrete subjected to axial and multiaxial states of stress, rate effects, time-dependent deformations, and multiscale modeling are covered. The behavior of reinforced concrete membrane elements subjected to plane states of stress, torsion, limit analysis is included, and an introduction to finite element modeling of reinforced concrete structures is given.

**[CEE 775 Mathematical and Computer Modeling of Material Behavior**

Spring. 3 credits. Prerequisites: T&AM 663 or equivalent course in solid mechanics and T&AM 611 or equivalent. Offered every other year; not offered 2004–2005. W. Aquino.

This course covers the fundamental physical and mathematical aspects of formulating material models for use in numerical schemes such as the finite element method. Possible topics covered in this course include basic plasticity and damage mechanics, numerical integration of plasticity equations, plastic-damage models, coupled models (temperature-deformation), and emerging techniques for constitutive modeling using neural networks and genetic algorithms. Applications include engineering materials such as concrete, soils, metals, and composites.]

**CEE 776 Advanced Topics in Stability**

Fall. 3 credits. Prerequisite: CEE 374 or equivalent. T. Pekoz.

Preliminary design of structural systems. Behavior and design of members and connections. Behavior and computer-aided design of building frames.

**CEE 777 Computational Solid and Structural Mechanics**

Spring. 3 credits. Prerequisites: T&AM 663 or CEE 471, CEE 671 with approval of instructor; CEE 672 or CEE 676 or equivalent background. Offered every other year. K. D. Papoulia.

This course covers the formulation and numerical solution of problems of solids and structures using the finite element method. Topics include a review of solid mechanics: nonlinear kinematics, invariance, 1st and 2nd law of thermodynamics, and constitutive equations with internal variables; strong forms and weak forms; implicit and explicit algorithms; variants of Newton's method;

and Lagrangian and Eulerian formulations. Application topics are chosen from the following areas: 3D finite elasticity, fully nonlinear beams and shells, distributed and discrete damage, contact-impact, and plasticity.

**[CEE 778 Natural Disaster Risk Assessment and Management**

Spring. 3 credits. Offered alternate years. Next offered spring 2005. R. A. Davidson.

This course explores ways to define, measure, and manage natural disaster risk using systems engineering, civil engineering, and social science perspectives and analysis tools. Multiple hazards and multiple viewpoints (local, international, individual, public sector, private sector) are considered.]

**CEE 783 Civil and Environmental Engineering Materials Project**

On demand. 1–3 credits. Staff.

Individual projects or reading and study assignments involving engineering materials.

**CEE 785 Research in Structural Engineering**

On demand. 1–6 credits. Staff.

Pursuit of a branch of structural engineering beyond what is covered in regular courses. Theoretical or experimental investigation of suitable problems.

**CEE 786 Fracture Mechanics**

Spring. 3 credits. L. Banks-Sills.

This course covers the basic principles of linear elastic fracture mechanics (LEFM): asymptotic expansion of stresses and displacements at a crack tip, Griffith's criterion, and plastic region at a crack tip. Topics include simple methods for calculating stress intensity factors; energy principles: energy release rate, compliance, and $J$-integral; experiments in fracture mechanics: plane strain fracture toughness $K_{Ic}$, plane stress and transition behavior, and mixed modes; and plasticity at the crack tip: HRR singularity, small- and large-scale yielding, $J$ dominance, and $J_{Ic}$ experiments.

**CEE 810 Thesis—Remote Sensing**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. W. D. Philpot.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 820 Thesis—Environmental and Water Resource Systems**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 821 Thesis—Environmental and Public Systems**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 830 Thesis—Fluid Mechanics and Hydrology**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 831 Thesis—Hydraulics/Hydrology**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 840 Thesis—Geotechnical Engineering**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others 'working on the same topic.

**CEE 850 Thesis—Environmental Engineering**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 851 Thesis—Environmental Quality Engineering**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 860 Thesis—Transportation Engineering**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

**CEE 880 Thesis—Structural Engineering**

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

# COMPUTER SCIENCE

C. Van Loan, chair; W. Arms, G. Bailey, K. Bala, K. Birman, C. Cardie, R. Caruana, T. Coleman, R. L. Constable, A. Demers, R. Elber, D. Fan, P. Francis, J. Gehrke, D. Greenberg, D. Gries, J. Halpern, J. E. Hopcroft, D. Huttenlocher, T. Joachims, U. Keich, J. Kleinberg, D. Kozen, L. Lee, S. Marschner, A. Myers, K. Pingali, R. Rugina, F. B. Schneider, D. Schwartz, B. Selman, J. Shanmugasundaram, D. Shmoys, E. G. Sirer, E. Tardos, R. Teitelbaum, S. Vavasis, G. Yona, R. Zabih

The Department of Computer Science is part of the College of Arts and Sciences, Computing and Information Science (CIS), and the College of Engineering. For complete course descriptions, see the Computer Science listing in the CIS section.

**COM S 099 Fundamental Programming Concepts**

Fall, summer. 2 credits. No prerequisites. S-U grades only. Credit cannot be applied toward the Engineering degree. Freshmen only.

**COM S 100 Introduction to Computer Programming**

Fall, spring, summer. 4 credits.

**COM S 100M Introduction to Computer Programming**

Corequisite: MATH 111, 191, or equivalent.

**COM S 100J Introduction to Computer Programming**

**COM S 101 Introduction to Cognitive Science (also COGST 101, LING 170, PHIL 191, and PSYCH 102)**

Fall, summer. 3 credits.

For description, see COGST 101.

**COM S 113 Introduction to C**

Fall, spring. 1 credit. Usually weeks 1–4. Prerequisite: COM S 100 or equivalent programming experience. Credit is granted for both COM S 113 and 213 only if 113 is taken first. S-U grades only.

**COM S 114 Unix Tools**

Fall. 1 credit. Usually weeks 5–8. Prerequisite: COM S 100 or equivalent programming experience. S-U grades only.

**COM S 130 Introductory Design and Programming for the Web (also INFO 130)**

Fall 3 credits. No prerequisites.

**COM S 165 Computing in the Arts (also CIS 165, MUSIC 165)**

Fall. 3 credits.

For description, see CIS 165.

**[COM S 172 Computation, Information, and Intelligence (also COGST 172 and ENGRI 172)**

Fall. 3 credits. Prerequisites: some knowledge of calculus. Not offered fall 2004.]

**COM S 201 Cognitive Science in Context Laboratory (also COGST 201 and PSYCH 201)**
Spring. 4 credits. Limited to 24 students. Prerequisite: concurrent or prior registration in Introduction to Cognitive Science (PSYCH 102/COGST 101/COM S 101/LING 170/PHIL 191) is suggested but not required. Knowledge of programming languages is not assumed. Fall, B. Halpern and staff; spring, D. Field and staff.
For description, see COGST 201.

**COM S 211 Computers and Programming (also ENGRD 211)**
Fall, spring, summer. 3 credits. Prerequisite: COM S 100 or an equivalent course in Java or C++.

**COM S 212 Java Practicum**
Fall, spring, summer. 1 credit. Letter grade only. Pre- or corequisite: COM S/ENGRD 211.

**[COM S 213 C++ Programming**
Spring. 2 credits. Prerequisite: COM S 100 or equivalent programming experience. Students who plan to take COM S 113 and 213 must take 113 first. S-U grades only.]

**COM S 214 Advanced UNIX Programming and Tools**
Spring. 1 credit. Usually weeks 5–8. Prerequisite: COM S 114 or equivalent. S-U grades only.

**COM S 215 Introduction to C#**
Fall, spring. 1 credit. Usually weeks 5–8. Prerequisite: COM S/ENGRD 211 or equivalent experience. S-U grades only.

**COM S 230 Intermediate Design and Programming for the Web (also INFO 230)**
Spring. 3 credits. Prerequisite: COM S 130 or equivalent knowledge.

**COM S 280 Discrete Structures**
Fall, spring. 3 credits. Pre- or corequisite: COM S/ENGRD 211 or permission of instructor.

**COM S 312 Data Structures and Functional Programming**
Fall, spring. 4 credits. Prerequisite: COM S 211/212 or equivalent programming experience. Should not be taken concurrently with COM S 314.

**COM S 314 Computer Organization (also ECE 314)**
Fall, spring. 4 credits. Prerequisite: COM S 211; COM S 312 or ENGRD 230 are recommended but not required. Should not be taken concurrently with COM S 312.

**[COM S 321 Numerical Methods in Computational Molecular Biology (also BIOBM 321 and ENGRD 321)**
Fall. 3 credits. Prerequisites: at least one course in calculus, such as MATH 106, 111, or 191 and a course in linear algebra, such as MATH 221 or 294 or BTRY 417. COM S 100 or equivalent and some familiarity with iteration, arrays, and procedures. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428. Not offered fall 2004.]

**COM S 322 Introduction to Scientific Computation (also ENGRD 322)**
Spring, summer. 3 credits. Prerequisites: COM S 100 and (MATH 221 or MATH 294). COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

**[COM S 324 Computational Linguistics (also COGST 424, LING 424)**
Fall, spring. 4 credits. Prerequisites: LING 203; labs involve work in the Unix environment; COM S 114 recommended.
For description, see LING 424.]

**COM S 330 Applied Database Systems (also INFO 330)**
Fall. 3 credits. Prerequisite: COM S 211/ENGRD 211. COM S majors may use only one of the following toward their degree: COM S/INFO 330 or COM S 433.

**COM S 381 Introduction to Theory of Computing**
Fall, summer. 3 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and COM S 481. Corrective transfers between COM S 381 and COM S 481 (in either direction) are encouraged during the first few weeks of instruction.

**COM S 400 The Science of Programming**
Fall. 3 credits. Prerequisite: COM S 211.

**COM S 411 Programming Languages**
Fall. 4 credits. Prerequisite: COM S 312 or permission of instructor.

**COM S 412 Introduction to Compilers**
Spring. 3 credits. Prerequisites: COM S 312 (or permission of instructor) and COM S 314. Corequisite: COM S 413.

**COM S 413 Practicum in Compilers**
Spring. 2 credits. Corequisite: COM S 412.

**COM S 414 Systems Programming and Operating Systems**
Fall, spring, summer. 3 credits. Prerequisite: COM S 211, 212, 312 (or permission of instructor), and 314. Corequisite: COM S 415 in spring only.

**COM S 415 Practicum in Operating Systems**
Fall, spring. 2 credits. Corequisite: COM S 414.

**COM S 419 Computer Networks (formerly COM S 519)**
Spring. 4 credits. Prerequisite: COM S 211, COM S 312, or ENGRD 230 are recommended but not required, or permission of instructor. Not offered every year.

**COM S 421 Numerical Analysis**
Fall. 4 credits. Prerequisites: MATH 294 or equivalent, one additional mathematics course numbered 300 or above, and knowledge of programming. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

**COM S 426 Introduction to Computational Biology**
Fall. 3 credits. Prerequisites: COM S/ENGRD 211, COM S 280.

**COM S 427 Practicum in Computational Biology**
Fall. 2 credits. Pre- or corequisite: COM S 426.

**COM S 428 Introduction to Computational Biophysics**
Fall. 3 credits. Prerequisite: COM S 100, CHEM 211 or equivalent, MATH 293 or 294, PHYS 112 or 213, or permission of instructor. BIOBM 330 recommended. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

**COM S 430 Information Retrieval (also INFO 430)**
Fall. 3 credits. Prerequisite: COM S 211 or equivalent.

**COM S 431 Web Information Systems (also INFO 431; formerly CIS 502)**
Spring. 3 credits. Prerequisites: COM S 211 and some familiarity with the technology of web sites.

**COM S 432 Introduction to Database Systems**
Fall. 3 credits. Prerequisites: COM S 312, or 211/212, and permission of instructor. Recommended: COM S 213 and strong programming skills in C or C++.

**COM S 433 Practicum in Database Systems**
Fall. 2 credits. Corequisite: COM S 432. COM S majors may use only one of the following toward their degree: COM S/INFO 330 or COM S 433.

**COM S 465 Computer Graphics I (also ARCH 374)**
Fall. 4 credits. Prerequisite: COM S/ENGRD 211. May not be taken after completion of COM S 417.

**COM S 467 Computer Graphics II**
Spring. 3 credits. Prerequisite: COM S 465.

**COM S 468 Computer Graphics Practicum**
Spring. 2 credits. Prerequisite: COM S 465. Corequisite: COM S 467.

**COM S 472 Foundations of Artificial Intelligence**
Fall. 3 credits. Prerequisites: COM S/ENGRD 211 and COM S 280 (or equivalent).

**COM S 473 Practicum in Artificial Intelligence**
Fall. 2 credits. Corequisite: COM S 472.

**COM S 474 Introduction to Natural Language Processing (also COGST 474, LING 474)**
Fall. 4 credits. Prerequisites: COM S 211.

**COM S 478 Machine Learning**
Spring. 4 credits. Prerequisites: COM S 280, 312, and basic knowledge of linear algebra and probability theory.

**COM S 480 Introduction to Cryptology (also MATH 335)**
Fall, spring. 3 credits. Prerequisites: COM S 100 and MATH 222 or 294. Students who take this course may not also receive credit for MATH 336.
For description, see MATH 335.

**COM S 481 Introduction to Theory of Computing**
Fall. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and 481. Corrective transfers between COM S 481 and 381 (in either direction) are encouraged during the first few weeks of instruction.

**COM S 482 Introduction to Analysis of Algorithms**
Spring, summer. 4 credits. Prerequisites: COM S 280, 312, and either 381 or 481, or permission of instructor.

**COM S 483 Quantum Computation (also PHYS 481 and 681)**
Spring. 2 credits. Prerequisite: familiarity with the theory of vector spaces over the complex numbers. Not offered every year.
For description, see PHYS 481.

**COM S 486 Applied Logic (also MATH 486)**
Fall or spring. 4 credits. Prerequisites: MATH 222 or 294, COM S 280 or equivalent (such as MATH 332, 432, 434, 481), and some additional course in mathematics or theoretical computer science.

**COM S 490 Independent Reading and Research**
Fall, spring. 1–4 credits.

**COM S 501 Software Engineering**
Spring. 4 credits. Prerequisite: COM S 211 or equivalent experience programming in Java or C++.

**COM S 504 Applied Systems Engineering (also CEE 504, ECE 512, M&AE 591, OR&IE 512, SYSEN 510)**
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor.
For description, see SYSEN 510.

**COM S 505 System Architecture, Behavior, and Optimization (also CEE 505, ECE 513, M&AE 592, OR&IE 513, SYSEN 520)**
Spring. 3 credits. Prerequisite: Applied System Engineering (CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512).
For description, see SYSEN 520.

**COM S 513 System Security**
Fall. 4 credits. Prerequisites: COM S 414 or 419 and familiarity with JAVA or C programming languages.

**COM S 514 Intermediate Computer Systems**
Spring. 4 credits. Prerequisites: COM S 414 or permission of instructor.

**COM S 522 Computational Tools and Methods for Finance**
Spring. 4 credits. Prerequisites: programming experience (e.g., C, FORTRAN, or MATLAB), some knowledge of numerical methods, especially numerical linear algebra. Not offered every year.

**COM S 530 The Architecture of Large-Scale Information Systems (also INFO 530)**
Spring. 4 credits. Prerequisite: COM S/INFO 330 or COM S 432.

**COM S 565 Computer Animation (also ART 372, CIS 565; formerly CIS/COM S 518)**
Fall. 4 credits. Prerequisite: COM S/ENGRD 211.
For description, see ART 372.

**COM S 572 Heuristic Methods for Optimization (also CEE 509, CIS 527, OR&IE 533)**
Spring. 3 or 4 credits. Prerequisites: COM S/ENGRD 211 or 322 or CEE/ENGRD 241, or graduate standing, or permission of instructor. Not offered every year.
For description, see CEE 509.

**COM S 578 Empirical Methods in Machine Learning and Data Mining**
Fall. 4 credits. Prerequisites: COM S 280 and 312 or equivalent.

**COM S 611 Advanced Programming Languages**
Fall. 4 credits. Graduate standing or permission of instructor.

**COM S 612 Compiler Design for High-Performance Architectures**
Spring. 4 credits. Prerequisites: COM S 314 and 412 or permission of instructor.

**COM S 614 Advanced Systems**
Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor.

**COM S 615 Peer-to-Peer Systems**
Spring. 4 credits. Prerequisites: COM S 614 recommended.

**COM S 619 Advanced Computer Networks**
Fall. 4 credits. Prerequisite: COM S 419 or COM S 519, or permission of instructor. Not offered every year.

**COM S 621 Matrix Computations**
Fall. 4 credits. Prerequisites: MATH 411 and 431 or permission of instructor.

**COM S 622 Numerical Optimization and Nonlinear Algebraic Equations**
Spring. 4 credits. Prerequisite: COM S 621. Offered odd-numbered years only.

**[COM S 624 Numerical Solution of Differential Equations**
Spring. 4 credits. Prerequisites: previous exposure to numerical analysis (e.g., COM S 421 or 621) and differential equations, and knowledge of MATLAB. Offered in even-numbered years.]

**COM S 626 Computational Molecular Biology**
Spring. 4 credits. Prerequisites: familiarity with linear programming, numerical solutions of ordinary differential equations, and nonlinear optimization methods.

**COM S 627 Computational Biology: The Machine Learning Approach**
Spring. 4 credits. Prerequisites: COM S 426 or 626 and COM S 478 or 578 or permission of instructor.

**COM S 630 Representing and Accessing Digital Information (also INFO 630)**
Fall. 4 credits. Prerequisites: COM S 472 or 478 or 578 or the equivalent.

**COM S 632 Database Systems**
Spring. 4 credits. Prerequisite: COM S 432/433 or permission of instructor.

**COM S 633 Advanced Database Systems**
Spring. 4 credits.

**COM S 664 Machine Vision**
Fall. 4 credits. Prerequisites: undergraduate-level understanding of algorithms and MATH 221 or equivalent.

**COM S 665 Advanced Rendering**
Fall or spring. 4 credits. Prerequisites: COM S 465 and 467 or equivalent and an undergraduate-level understanding of algorithms, probability and statistics, vector calculus, and programming.

**COM S 667 Physically Based Rendering**
Fall or spring. 4 credits. Prerequisites: COM S 465 and 467 or equivalent and an undergraduate-level understanding of algorithms, programming, and vector calculus.

**COM S 671 Introduction to Automated Reasoning**
Fall or spring. 4 credits. Prerequisite: (COM S 611 and graduate standing) or permission of instructor.

**COM S 672 Advanced Artificial Intelligence**
Spring. 4 credits. Prerequisites: COM S 472 or permission of instructor.

**COM S 673 Integration of Artificial Intelligence and Operations Research (also CIS 673)**
Spring. 3 credits.

**COM S 674 Natural Language Processing**
Spring. 3 credits. Prerequisites: COM S 472 or permission of instructor. COM S 474 is NOT a prerequisite. Not offered every year.

**[COM S 676 Reasoning about Knowledge**
Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic.]

**[COM S 677 Reasoning about Uncertainty**
Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic.]

**COM S 678 Advanced Topics in Machine Learning**
Spring. 4 credits. Prerequisites: COM S 478 or equivalent, or COM S 578 or equivalent, or permission of instructor.

**COM S 681 Analysis of Algorithms**
Fall. 4 credits. Prerequisite: COM S 482 or graduate standing.

**COM S 682 Theory of Computing**
Spring. 4 credits. Prerequisite: COM S 381 or 481 and COM S 482 or 681 or permission of instructor.

**[COM S 683 Advanced Design and Analysis of Algorithms**
Spring. 4 credits. Prerequisites: COM S 681 or permission of instructor. Not offered every year.]

**[COM S 684 Algorithmic Game Theory**
Spring. 4 credits. Prerequisites: COM S 681 or permission of instructor. Not offered every year.]

**COM S 685 The Structure of Information Networks (also INFO 685)**
Spring. 4 credits. Prerequisite: COM S 482.

**[COM S 686 Logics of Programs**
Spring. 4 credits. Prerequisites: COM S 481, 682, and MATH 481 or MATH/COM S 486. Not offered every year.]

**COM S 709 Computer Science Colloquium**
Fall, spring. 1 credit. S-U grades only. For staff, visitors, and graduate students interested in computer science.

**COM S 711 Seminar in Advanced Programming Languages**
Fall, spring. 3 credits.

**COM S 713 Seminar in Systems and Methodology**
Fall, spring. 4 credits. Prerequisites: a graduate course employing formal reasoning such as COM S 611, 613, 671, a logic course, or permission of instructor. Not offered every year.

**COM S 715 Seminar in Programming Refinement Logics**
Fall, spring. 4 credits. Prerequisite: permission of instructor.

**COM S 717 Topics in Parallel Architectures**
Fall. 4 credits. Prerequisite: COM S 612 or permission of instructor. Not offered every year.

**COM S 718 Computer Graphics Seminar**
Fall, spring. 4 credits.

**COM S 719 Seminar in Programming Languages**
Fall, spring. 4 credits. Prerequisite: COM S 611 or permission of instructor. S-U grades only.

**COM S 721 Topics in Numerical Analysis**
Fall, spring. 4 credits. Prerequisite: COM S 621 or 622 or permission of instructor.

**COM S 726 Problems and Perspectives in Computational Molecular Biology (also PL BR 726)**
Fall, spring. 1 credit. S-U grades only.

**COM S 732 Seminar in Database Systems**
Fall, spring. 4 credits. S-U grades only.

**COM S 750 Evolutionary Computation and Design Automation (also CIS 750, MAE 650)**
Fall. 4 credits. Prerequisite: programming experience or permission of instructor.

**[COM S 751 Media Research and Critical Design (also CIS 751)**
Fall. 4 credits. Prerequisites: graduate standing in COM S or equivalent ability to read technical research papers. Contact instructor if unsure of qualifications. Not offered every year.]

**[COM S 752 Seminar on Scholarly Information Architecture (also CIS 752)**
Fall. 3 credits. Prerequisite: concurrent enrollment in COM S 502 or equivalent experience. S-U grades only. Not offered every year.]

**COM S 754 Systems Research Seminar**
Fall, spring. 1 credit. S-U grades only.

**COM S 772 Seminar in Artificial Intelligence**
Fall, spring. 4 credits. Prerequisites: permission of instructor. S-U grades only.

**COM S 775 Seminar in Natural Language Understanding**
Fall, spring. 2 credits.

**COM S 786 Introduction to Kleene Algebra**
Spring. 4 credits. Prerequisites: COM S 481 required; COM S 482 or 681, COM S 682, elementary logic (MATH 481 or 681), algebra (MATH 432) recommended.

**COM S 789 Seminar in Theory of Algorithms and Computing**
Fall, spring. 4 credits. Prerequisite: permission of instructor. S-U grades only.

**COM S 790 Special Investigations in Computer Science**
Fall, spring. Prerequisite: permission of a computer science adviser. Letter grade only.

**COM S 990 Special Investigations in Computer Science**
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only. Doctoral research.

## EARTH AND ATMOSPHERIC SCIENCES

T. E. Jordan, chair; S. J. Colucci, co-chair (CALS); directors of undergraduate studies: B. L. Isacks (Geological Sciences and Science of Earth Systems—A&S), S. J. Riha (Science of Earth Systems—CALS), M. W. Wysocki (Atmospheric Sciences); and R. W. Allmendinger, W. D. Allmon, M. Barazangi, W. Bassett, J. M. Bird, A. L. Bloom, L. D. Brown, L. M. Cathles, J. L. Cisne, K. H. Cook, A. T. DeGaetano, L. A. Derry, P. J. Gierasch, C. H. Greene, D. L. Hysell, D. E. Karig, R. W. Kay, S. Mahlburg Kay, M. C. Kelley, W. W. Knapp, J. E. Oliver, A. J. Pershing, J. Phipps Morgan, M. Pritchard, F. H. T. Rhodes, D. L. Turcotte, W. M. White, D. S. Wilks

For complete course descriptions, see the Earth and Atmospheric Sciences listing in the College of Arts and Sciences or the College of Agriculture and Life Sciences section.

**EAS 101 Introductory Geological Sciences**
Fall. 3 credits. Staff.

**EAS 102 Evolution of the Earth and Life (also offered as BIO G 170)**
Spring. 3 credits. J. L. Cisne.

**EAS 103 SES Freshman Colloquium**
Fall. 1 credit. TBA.

**EAS 107 How the Earth Works**
Fall. 1 credit. J. L. Cisne.

**EAS 108 Earth in the News**
Summer. 3 credits. S. L. Losh.

**EAS 109 Dinosaurs**
Fall. 1 credit. J. L. Cisne.

**[EAS 111 To Know the Earth**
Fall. 3 credits. Not offered 2004–2005. Staff.]

**EAS 121 Introduction to MATLAB (also CIS 121)**
Fall, spring. 2 credits. Prerequisites: MATH 111, 191, or equivalent. D. Schwartz.

**EAS 122 Earthquake! (also ENGRI 122)**
Spring. 3 credits. L. D. Brown.
This is a course in the Introduction to Engineering series. For description, see ENGRI 122.

**EAS 131 Basic Principles of Meteorology**
Fall. 3 credits. M. W. Wysocki.
The one-credit laboratory for this course is EAS 133.

**EAS 133 Basic Meteorology Lab**
Fall. 1 credit. Laboratory. Prerequisite: concurrent enrollment in EAS 131. M. W. Wysocki.
Laboratory course covering topics presented in EAS 131. This course is required for atmospheric science majors, but is optional for other students taking EAS 131.

**EAS 150 Fortran Applications in Earth Science**
Spring. 2 credits. Prerequisite: CIS/EAS 121 or equivalent. LET only. A. J. Pershing.

**EAS 154 The Sea: An Introduction to Oceanography (also BIOEE 154)**
Spring, summer. 3 credits. Lecture. Spring: C. H. Greene, W. M. White; summer: B. C. Monger. The optional one-credit laboratory for this course is EAS 155/BIOEE 155.

**EAS 155 The Sea: An Introduction to Oceanography (also BIOEE 155)**
Spring. 1 credit. Laboratory. Prerequisite: Concurrent enrollment in EAS 154. C. H. Greene.
Laboratory course covering topics presented in EAS 154.

**[EAS 200 Art, Archaeology, and Analysis (also ENGRI 185, or MS&E 285)**
Spring. 3 credits. Not offered 2004–2005.]

**EAS 201 Introduction to the Physics and Chemistry of the Earth (also ENGRD 201)**
Fall. 3 credits. Prerequisites: PHYS 112 or 207. J. Phipps Morgan, L. Cathles.

**EAS 203 Fundamental Principles of Earth Science**
Fall. 3 credits. Letter grade only. Prerequisite: modest science background advantageous. L. M. Cathles, J. Phipps Morgan.

**EAS 210 Introduction to Field Methods in Geological Sciences**
Fall. 3 credits. Prerequisites: EAS 101 or 201, or permission of instructor. 1 lecture, Saturday field trips. R. W. Allmendinger.

**EAS 213 Marine and Coastal Geology**
Summer. 4 credits. Prerequisite: an introductory course in geology or ecology or permission of instructor. Staff.

**EAS 222 Seminar—Hawaii's Environment**
Fall. 1 credit. S-U grade only. A. Moore. L. Derry.

**EAS 240 Field Study of the Earth System**
Spring. 5 credits. Prerequisites: one semester of calculus (MATH 191, 192, 193 or MATH 111, 112) and two semesters of any of the following: PHYS 207/208 or 112/213; CHEM 207/208; BIOG 101/103–102/104 or 105/106 or 109/110; or equivalent course work. Limited to those enrolled in Cornell Abroad Earth and Environmental Sciences Semester in Hawaii. A. Moore and M. Wysocki.

**EAS 250 Meteorological Observations and Instruments**
Fall. 3 credits. Prerequisite: EAS 131. M. W. Wysocki.

**EAS 268 Climate and Global Warming**
Spring. 3 credits. Prerequisite: basic college math. A. T. DeGaetano.

**EAS 296 Forecast Competition**
Fall and spring. 1 credit. S-U grades only. Prerequisite: sophomore undergraduate standing in atmospheric science, or permission of instructor. D. S. Wilks.

**EAS 302 Evolution of the Earth System**
Spring. 4 credits. Prerequisites: MATH 112 or 192 and CHEM 207 or equivalent. W. M. White, W. D. Allmon, B. L. Isacks.

**EAS 315 Geomorphology**
Fall. 4 credits. Prerequisite: one course in geology, hydrology, or soil science. B. L. Isacks.

**EAS 321 Introduction to Biogeochemistry (also NTRES 321)**
Fall. 4 credits. Prerequisites: CHEM 207, MATH 112, plus a course in biology and/or geology. L. A. Derry, J. Yavitt.

**EAS 322 Biogeochemistry of the Hawaiian Islands**
Spring. 4 credits. Prerequisite: BIOEE 261, EAS 321, EAS 455, or permission of instructor. Limited to those enrolled in Cornell Abroad Earth and Environmental Sciences Semester in Hawaii. L. Derry.

**EAS 326 Structural Geology**
Spring. 4 credits. Prerequisite: one semester of calculus plus an introductory geology course or permission of instructor. One weekend field trip. R. W. Allmendinger.

**EAS 331 Climate Dynamics (also ASTRO 331)**
Fall. 4 credits. Prerequisite: two semesters of calculus and one semester of physics. K. H. Cook, P. J. Gierasch.

**[EAS 334 Microclimatology**
Spring. 3 credits. Prerequisite: a course in physics. Offered alternate years. D. S. Wilks.]

**EAS 341 Atmospheric Thermodynamics and Hydrostatics**
Fall. 3 credits. Prerequisites: 1 year of calculus and 1 semester of physics. A. T. DeGaetano.

**EAS 342 Atmospheric Dynamics (also ASTRO 342)**
Spring 3 credits. Prerequisites: 1 year each of calculus and physics. K. H. Cook and P. J. Gierasch.

**[EAS 350 Dynamics of Marine Ecosystems (also BIOEE 350)**
Fall. 3 credits. Prerequisites: 1 year of calculus and a semester of oceanography (i.e., EAS 154), or instructor's permission. C. H. Greene and R. W. Howarth.]

**EAS 351 Marine Ecosystems Field Course (BIOEE 351)**
Spring. 4 credits. Prerequisites: one semester of calculus (MATH 191, 192, 193 or MATH 111, 112), two semesters of biology (BIOG 101/103–102/104 or 105/106 or 109/110); one semester of oceanography (EAS 154) is recommended. Limited to those enrolled in Cornell Abroad Earth and Environmental Sciences Semester in Hawaii. C. Greene, B. Monger.

**EAS 352 Synoptic Meteorology I**
Spring. 3 credits. Prerequisites: EAS 341 and concurrent enrollment in EAS 342. M. W. Wysocki.

**EAS 355 Mineralogy**
Fall. 4 credits. Prerequisites: EAS 101 or 201 and CHEM 207/211 or permission of instructor. S. Mahlburg Kay.

**EAS 356 Petrology and Geochemistry**
Spring. 4 credits. Prerequisite: EAS 355. R. W. Kay.

**EAS 375 Sedimentology and Stratigraphy**
Fall. 4 credits. Prerequisite: EAS 101 or 201. J. L. Cisne.

**EAS 388 Geophysics and Geotectonics**
Spring. 4 credits. Prerequisites: MATH 192 (or 112) and PHYS 208 or 213. B. L. Isacks.

**EAS 401 Fundamentals of Energy and Mineral Resources**
Spring. 3 credits. L. Cathles.

**EAS 417 Field Mapping in Argentina**
Summer. 3 credits. Prerequisites: EAS 210 and 326; Spanish desirable but not required. S. Mahlburg Kay.

**EAS 434 Reflection Seismology**
Fall. 3 credits. Prerequisites: MATH 192 and PHYS 208, 213, or equivalent. L. D. Brown.

**EAS 435 Statistical Methods in Meteorology and Climatology**
Fall. 3 credits. Prerequisites: an introductory course in statistics (e.g., AEM 210) and calculus. D. S. Wilks.

**[EAS 437 Geophysical Field Methods**
Fall. 3 credits. Prerequisite: PHYS 213 or 208 or permission of instructor. Offered alternate years. L. D. Brown.]

**EAS 445 Introduction to Groundwater Hydrology (also BEE 471/CEE431)**
Spring. 3 credits. Prerequisites: MATH 294 and ENGRD 202. L. Cathles.

**[EAS 447 Physical Meteorology**
Fall. 3 credits. Prerequisites: 1 year each of calculus and physics. Offered alternate years. A. T. DeGaetano.]

**EAS 451 Synoptic Meteorology II**
Fall. 3 credits. Prerequisites: EAS 341 and 342. S. J. Colucci.

**[EAS 453 Advanced Petrology**
Fall. 3 credits. Prerequisite: EAS 356. Offered alternate years. R. W. Kay.]

**[EAS 454 Advanced Mineralogy**
Spring. 3 credits. Prerequisite: EAS 355 or permission of instructor. Offered alternate years. Not offered 2004–2005. S. M. Kay.]

**[EAS 455 Geochemistry**
Fall. 4 credits. Prerequisites: CHEM 207 and MATH 192 or equivalent. Recommended: EAS 356. Offered alternate years. W. M. White.]

**[EAS 456 Mesoscale Meteorology**
Spring. 3 credits. Prerequisites: EAS 341 and 342 or permission of instructor. Offered alternate years. Not offered 2004–2005. S. J. Colucci.]

**EAS 457 Atmospheric Air Pollution**
Fall. 3 credits. Prerequisites: EAS 341 or 1 course in thermodynamics, and one semester of chemistry, or permission of instructor. Offered alternate years. M. W. Wysocki.

**EAS 458 Volcanology**
Fall. 3 credits. Prerequisite: EAS 356 or equivalent. Offered alternate years. R. W. Kay and W. M. White.

**EAS 460 Late Quaternary Paleoecology**
Fall. 3 credits. M. Goman.

**EAS 462 Marine Ecology (also offered as BIOEE 462)**
Fall. 3 credits. Limited to 75 students. Prerequisite: BIOEE 261. Offered alternate years. C. D. Harvell, C. H. Greene.

**EAS 470 Weather Forecasting and Analysis**
Spring. 3 credits. Prerequisites: EAS 352 and EAS 451. M. W. Wysocki.

**EAS 475 Special Topics in Oceanography**
Fall, spring, summer. 2–6 var. credits. Prerequisites: one semester of oceanography and permission of instructor. Fall, spring: C. H. Greene; summer: B. C. Monger.

**EAS 476 Sedimentary Basins: Tectonics and Mechanics**
Fall. 3 credits. Prerequisite: EAS 375 or permission of instructor. Offered alternate years. T. E. Jordan.

**[EAS 478 Advanced Stratigraphy**
Fall. 3 credits. Prerequisite: EAS 375 or permission of instructor. Offered alternate years. Not offered 2004–2005. T. E. Jordan.]

**[EAS 479 Paleobiology (also BIOEE 479)**
Fall. 4 credits. Prerequisites: 1 year of introductory biology and either BIOEE 274 or 373 or EAS 375, or permission of instructor. Offered alternate years. Not offered 2004–2005. W. Allmon.]

**[EAS 481 Senior Survey of Earth Systems**
Spring. 3 credits. Limited to seniors majoring in geological science. Not offered 2004–2005. Staff.]

**EAS 483 Environmental Biophysics**
Spring. 3 credits. Offered alternate years. S. J. Riha.

**EAS 487 Introduction to Radar and Remote Sensing (also ECE 487)**
Fall. 3 credits. Prerequisites: PHYS 208 or 213 or equivalent or permission of instructor. D. L. Hysell.

**EAS 491–492 Undergraduate Research**
Fall, spring. 1–4 credits. Staff.

**EAS 494 Special Topics in Atmospheric Science**
Fall, spring. 8 credits maximum. S-U grades optional. Undergraduate level. Staff.

**EAS 496 Internship Experience**
Fall, spring. 1–2 credits. S-U grades only. Staff.

**EAS 497 Individual Study in Atmospheric Science**
Fall, spring. 1–6 credits. S-U grades optional. Students must register with an Independent Study form. Staff.

**EAS 498 Teaching Experience in Earth and Atmospheric Sciences**
Fall, spring. 1–4 credits. S-U grades only. Students must register with an Independent Study form. Staff.

**EAS 499 Undergraduate Research in Atmospheric Science**
Fall, spring. Credit by arrangement. S-U grades only. Students must register with an Independent Study form. Staff.

**EAS 500 Design Project in Geohydrology**
Fall. spring. 3–12 credits. An alternative to an industrial project for M.Eng. students choosing the geohydrology option. May continue over two or more semesters. L. M. Cathles.

**EAS 502 Case Histories in Groundwater Analysis**
Spring. 4 credits. L. M. Cathles.

**[EAS 622 Advanced Structural Geology I**
Spring. 3 credits. Prerequisites: EAS 326 and permission of instructor. Offered alternate years. R. W. Allmendinger.]

**EAS 624 Advanced Structural Geology II**
Spring. 3 credits. Prerequisites: EAS 326 and permission of instructor. Offered alternate years. R. W. Allmendinger.

**[EAS 628 Geology of Orogenic Belts**
Spring. 3 credits. Prerequisite: permission of instructor. Not offered 2004–2005. Staff.]

**[EAS 634 Advanced Geophysics I**
Fall. 3 credits. Prerequisite: EAS 388 or permission of instructor. Offered alternate years. Not offered 2004–2005.]

**EAS 636 Advanced Geophysics II: Quantitative Geodynamics**
Spring. 3 credits. Prerequisite: EAS 388 or permission of instructor. Offered alternate years. J. Phipps Morgan.

**EAS 641 Analysis of Biogeochemical Systems**
Spring. 3 credits. Prerequisite: MATH 293 or permission of instructor. Offered alternate years. L. A. Derry.

**EAS 651 Atmospheric Physics (also ASTRO 651)**
Fall. 3 credits. Prerequisite: a good background in undergraduate calculus and physics is required. Offered alternate years. K. H. Cook, P. J. Gierasch, S. J. Colucci.

**EAS 652 Advanced Atmospheric Dynamics (also ASTRO 652)**
Spring. 3 credits. Prerequisites: EAS 341 and 342 or their equivalent. Offered alternate years. S. J. Colucci, P. J. Gierasch.

**EAS 656 Isotope Geochemistry**
Spring. 3 credits. Open to undergraduates. Prerequisite: EAS 455 or permission of instructor. Offered alternate years. W. M. White.

**EAS 666 Applied Multivariate Statistics**
Spring. 3 credits. Prerequisites: multivariate calculus, matrix algebra, and two previous courses in statistics. Offered alternate years. D. S. Wilks.

**[EAS 675 Modeling the Soil-Plant-Atmosphere System**
Spring. 3 credits. Prerequisite: EAS/CSS 483 or equivalent. Offered alternate years. S. J. Riha.]

**EAS 692 Special Topics in Atmospheric Science**
Fall. spring. 1–6 credits. S-U grades optional. Staff.

**EAS 695 Computer Methods in Geological Sciences**
Fall, spring. 3 credits. L. Brown, B. L. Isacks.

**EAS 700–799 Seminars and Special Work**
Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.

**EAS 711 Upper Atmospheric and Space Physics**
D. L. Hysell.

**EAS 722 Advanced Topics in Structural Geology**
R. W. Allmendinger.

**EAS 731 Planetary Geodynamics, Active Tectonics, Volcanology, Earthquakes, and Geodesy**
M. Pritchard.

**EAS 733 Advanced Topics in Geodynamics**
Spring. J. Phipps Morgan.

**EAS 751 Petrology and Geochemistry**
R. W. Kay.

**EAS 755 Geodynamics**
Fall. 3 credits. J. Phipps Morgan.

**EAS 757 Current Research in Petrology and Geochemistry**
S. Mahlburg Kay.

**EAS 762 Advanced Topics in Paleobiology**
W. D. Allmon.

**EAS 771 Advanced Topics in Sedimentology and Stratigraphy**
T. E. Jordan.

**EAS 773 Paleobiology**
J. L. Cisne.

**EAS 775 Advanced Topics in Oceanography**
Spring. C. H. Greene.

**EAS 777 Advanced Topics in Climate Dynamics**
Spring. K. Cook.

**EAS 780 Earthquake Record Reading**
Fall. M. Barazangi.

**EAS 781 Geophysics, Exploration Seismology, Ground-Penetrating Radar**
L. D. Brown.

**EAS 783 Advanced Topics in Geophysics**
B. L. Isacks.

**EAS 789 Lithospheric Seismology**
L. D. Brown.

**EAS 793 Andes-Himalaya Seminar**
S. Mahlburg Kay, R. W. Allmendinger, B. L. Isacks, T. E. Jordan.

**EAS 795 Low Temperature Geochemistry**
1–3 credits. S-U grades only. L. A. Derry.

**EAS 796 Geochemistry of the Solid Earth**
W. M. White.

**EAS 797 Fluid-Rock Interactions**
L. M. Cathles.

**EAS 799 Soil, Water, and Geology Seminar**
Spring. L. M. Cathles, T. S. Steenhuis.

**EAS 850 Master's-Level Thesis Research in Atmospheric Science**
Fall, spring. Credit by arrangement. S-U grades only. Hours by arrangement. Graduate faculty.

**EAS 950 Graduate-Level Dissertation Research in Atmospheric Science**
Fall, spring. Credit by arrangement. S-U grades optional. Hours by arrangement. Graduate faculty.

**EAS 951 Doctoral-Level Dissertation Research in Atmospheric Science**
Fall, spring. Credit by arrangement. S-U grades optional. Hours by arrangement. Graduate faculty.

## ELECTRICAL AND COMPUTER ENGINEERING

C. R. Pollock, director; C. E. Seyler, associate director; D. H. Albonesi, A. B. Apsel, J. M. Ballantyne, T. Berger, A. W. Bojanczyk, M. Burtscher, H.-D. Chiang, D. F. Delchamps, L. F. Eastman, D. T. Farley, T. L. Fine, W. K. Fuchs, Z. Haas, D. A. Hammer, S. S. Hemami, C. R. Johnson, Jr., E. Kan, M. C. Kelley, P. M. Kintner, R. R. Kline, K. T. Kornegay, A. Lal, M. Lipson, R. Manohar, J. F. Martínez, S. A. McKee, T. W. Parks, F. Rana, A. P. Reeves, A. Scaglione, S. Servetto, J. R. Shealy, M. G. Spencer, C. L. Tang, R. J. Thomas, S. Tiwari, L. Tong, S. B. Wicker

**ECE 210 Introduction to Circuits for Electrical and Computer Engineers (also ENGRD 210)**
Fall, spring. 3 or 4 credits. Corequisites: MATH 293 and PHYS 213. ECE majors must take 4 credits, includes a design project. Non-ECE majors can take 3 credits. All students must take a lab and a section. Fall, J. C. Belina, C. E. Seyler; spring, staff.
For description, see ENGRD 210.

**ECE 220 Signals and Information**
Fall, spring. 3 or 4 credits. Prerequisite: MATH 293. ECE majors must take 4 credits. Fall, S. S. Hemami; spring, C. R. Johnson.
An introductory course in signal processing. Topics include frequency-based representations: Fourier series and discrete Fourier transform; discrete time linear systems: input/output relationships, filtering, spectral response; analog-to-digital and digital-to-analog conversion; continuous time signals and linear time invariant systems: frequency response and continuous-time Fourier transform.

**[ECE 250 Technology in Society (also ENGRG 250, HIST 250 and S&TS 250)**
Fall. 3 credits. A humanities elective for engineering students. Not offered 2004–2005.
For description, see ENGRG 250.]

**ECE 291–292 Sophomore Electrical and Computer Engineering Project**
Fall, 291; spring, 292. 1–8 credits. Limited to sophomores in Engineering. Staff.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor

prior to registration and submit a request for Independent Project form to the Electrical and Computer Engineering Undergraduate Office.

**ECE 298 Inventing an Information Society (also AM ST 292, ENGRG 298, HIST 292, and S&TS 292)**

Spring. 3 credits. Approved for humanities distribution. R. R. Kline.

For description, see ENGRG 298.

**ECE 303 Electromagnetic Fields and Waves**

Fall. 4 credits. Prerequisites: grades of C or better in PHYS 213, 214, and MATH 294. D. T. Farley.

Maxwell's equations in differential form; wave equation; plane electromagnetic waves; phase and group velocities; Poynting's theorem, complex dielectric constant; wave reflection and transmission; guided waves on transmission lines; transient pulse propagation; and elementary dipole antenna; analysis of wireless communication links.

**ECE 306 Fundamentals of Quantum and Solid-State Electronics**

Spring. 4 credits. Prerequisites: PHYS 214 and MATH 294. C. L. Tang.

Introductory quantum mechanics and solid-state physics necessary for modern solid-state electronic devices. Topics include the formalism and methods of quantum mechanics, the hydrogen atom, the structure of simple solids, energy bands, Fermi-Dirac statistics, and the basic physics of semiconductors. Applications include quantum wells and the p-n junction.

**ECE 310 Introduction to Probability and Random Signals**

Spring. 4 credits. Prerequisite: MATH 294. This course may be used in place of ENGRD 270 to help satisfy the engineering distribution requirement. T. L. Fine.

Introduction to the theory of probability as a basis for modeling random phenomena and signals, calculating the response of systems, and making estimates, inferences, and decisions in the presence of chance and uncertainty. Applications are given in such areas as communications, and device modeling, probability, and characteristic functions; nonlinear transformations of data; expectation and correlation; and the central limit theorem.

**ECE 311 Electrical and Computer Engineering Honors Seminar**

Spring. 1 or 2 credits. Staff.

Students registered for this course are required to attend all of the colloquia lectures. Summary papers are required. Honors students who take the seminar for letter grade are required to write two summary papers for two credits. Non-honors students, who must take the seminar pass/fail, are required to write one summary paper for one credit. Each summary paper reviews a topic presented during the term.

**ECE 314 Computer Organization (also COM S 314)**

Fall, spring. 4 credits. Prerequisites: COM S/ENGRD 211 or ENGRD 230 required. Fall, COM S staff; spring, staff.

Course description for spring offering: basic computer organization. Topics include performance metrics, data formats, instruction sets, addressing modes, computer arithmetic, microcoded and pipelined datapath design, memory hierarchies including caches and virtual memory, I/O devices, bus-based I/O systems. Students learn assembly language programming and design a simple pipelined processor. For fall description, see COM S 314.

**ECE 315 Introduction to Microelectronics**

Fall, spring. 4 credits. Prerequisites: ECE/ ENGRD 210. Staff.

Design of digital and analog electronic circuits in the context of modern integrated circuit technology. Course coverage includes the building blocks of integrated circuits: introductory physics of semiconductors, MOS and junction transistors; digital electronics—inverters, logic circuits, and memory; and analog circuits—multi-stage and differential amplifiers.

**ECE 320 Networks and Systems**

Spring. 4 credits. Prerequisites: ECE 220 and MATH 294. S. B. Wicker.

Students develop a working understanding of the analytical and computational tools used in the design and representation of complex networks and systems. Topics include state-space techniques, finite state machines, graph-theoretic approaches to network design and analysis, complexity, phase transitions in complex systems, and scalability.

**ECE 336 Nanofabrication (also ECE 536 and MS&E 541)**

Spring. 3–5 credits. Prerequisites: PHYS 213 or 217, PHYS 214 or 218; CHEM 211 or 207; or equivalent. D. Ast.

For description, see MS&E 541.

**ECE 391–392 Junior Electrical and Computer Engineering Project**

Fall, 391; spring, 392. 1–8 credits. Limited to juniors in Engineering.

Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor prior to registration and submit a Request for Independent Project form to the Electrical Engineering Undergraduate Office.

**ECE 402 Biomedical System Design (also BMEP 404)**

Spring. 1–4 credits. Co- or prerequisites: at least one of: ECE 425, ECE 476, ECE 453. J. C. Belina.

Course introduces techniques of measuring and conditioning low-level (biological) signals. Topics include special signal to noise improvement circuits for analog signals, techniques to remove common-mode and correlated noise, and computer-aided techniques for analyzing sampled data. Final 6 or 7 weeks devoted to designing/prototyping a safe and effective "ambulatory microprocessor-controlled blood pressuremonitor." Formal design document is required. ECE 402 is a culminating design experience (CDE) course.

**ECE 411 Random Signals in Communications and Signal Processing**

Fall. 3 credits. Prerequisite: ECE 310 or equivalent. A. Scaglione.

Introduction to models for random signals in discrete and continuous time; Markov chains, Poisson process, queuing processes, power spectral densities, Gaussian random process. Response of linear systems to random signals. Elements of estimation and inference as they arise in communications and digital signal processing systems.

**ECE 413 Introduction to Nuclear Science and Engineering**

Fall. 3 credits. Prerequisites: PHYS 214 and MATH 294. K. B. Cady.

This course is designed for juniors or seniors from any engineering field who want to prepare for graduate-level nuclear science and engineering courses at Cornell or elsewhere. It also can serve as a basic course for those who do not intend to continue in the field. It is an introduction to the fundamentals of nuclear reactors. Topics include an overview of the field of nuclear engineering; nuclear structure, radioactivity, and reactions; interaction of radiation and matter; and neutron moderation, neutron diffusion, the steady-state chain reaction, and reactor kinetics.

**ECE 415 GPS: Theory and Design (also M&AE 415)**

Fall. 4 credits. Prerequisite: a 300-level engineering course with advanced math content such as ECE 303, or MAE 326. P. M. Kintner.

An analysis of GPS operating principles and engineering practice with a culminating design exercise. Navigational algorithms, receiver analysis, error investigation, dilution of precision, antennas, differential GPS. ECE 415 is a culminating design experience (CDE) course.

**ECE 425 Digital Signal Processing**

Fall. 4 credits. Prerequisites: ECE 220, ECE 320, and ECE 310. T. W. Parks, B. A. Hutchins.

An advanced course in digital signal processing. Topics include sampling, A/D and D/A conversion, digital filter design and implementation, multirate DSP including sampling rate conversion and filter bank theory, Wiener filtering, spectral estimation, introduction to two-dimensional sampling, and Fourier techniques.

**ECE 426 Applications of Signal Processing**

Spring. 4 credits. Prerequisite: ECE 425. B. A. Hutchins.

Applications of signal processing, including signal analysis, filtering, and signal synthesis. The course is laboratory oriented, emphasizing individual student projects. Design is done with signal-processing hardware and by computer simulation. Topics include filter design, spectral analysis, speech coding, speech processing, digital recording, adaptive noise cancellation, and digital signal synthesis. ECE 426 is a culminating design experience (CDE) course.

**ECE 430 Lasers and Optical Electronics**

Fall. 4 credits. Prerequisite: ECE 303 or equivalent. C. R. Pollock.

An introduction to the operation and application of lasers. Material covered includes diffraction-limited optics, Gaussian beams, optical resonators, interaction of radiation with matter, physics of laser operation, and laser design. Applications of coherent radiation to nonlinear optics, communication, and research are discussed.

**ECE 432 MicroElectro Mechanical Systems (MEMS)**

Spring. 3 credits. Prerequisite: ECE 315 or permission of instructor. A. Lal.

Introductory course to MEMS: microsensors, microactuators, and microrobots. Fundamentals of MEMS, including materials, microstructures, devices and simple microelectro-mechanical systems, scaling electronic and mechanical systems to the micrometer/nm-scale, material issues, and the integration of micromechanical structures and actuators with simple electronics. This is an interdisciplinary course drawing content from mechanics, materials, structures, electronic systems, and the disciplines of physics and chemistry. ECE 432 is a culminating design experience (CDE) course.

**ECE 433 Introduction to Microwave Devices and Circuits**

Fall. 4 credits. Prerequisites: ECE 303 and ECE 306. J. R. Shealy.

An introduction to the properties of microwave devices and circuits and the considerations that must be appreciated when the operating frequency approaches or exceeds 1 GHz. Topics include microwave devices, microwave measurement techniques, S-parameters, signal flow diagrams, matching networks, basic circuit design considerations, and computer-aided device and circuit analysis. Laboratories cover basic measurement techniques for active and passive elements as well as low noise amplifier design.

**ECE 437 Fiber and Integrated Optics**

Spring. 4 credits with a project. Prerequisite: ECE 303 or equivalent. M. Lipson.

Physical principles of optical waveguides. Wave equation solutions to the mode structure in waveguides, numerical analysis, mode coupling, dispersion and bandwidth limitations, optical materials, photonic band gap structures. Project design of planar optical components. ECE 437 is a culminating design experience (CDE) course.

**[ECE 445 Computer Networks and Telecommunications**

Fall. 4 credits. Prerequisites: ECE or COM S 314 and a course in probability. Not offered 2004–2005.

This is a basic course in networking covering the design, analysis, and implementation of computer and communication networks and systems. Topics covered include data transmission and data encoding, data link control, circuit vs. packet switching, Asynchronous Transfer Mode, local area network technology, network interconnections, protocol design (OSI and IP), network security, and multimedia. Emphasis is placed on performance evaluation.]

**ECE 446 Digital Communications Over Packet-Switched Networks**

Spring. 4 credits. Prerequisites: ECE or COM S 314 and a course in probability.

This is a basic course in networking covering the design and performance analysis of communication systems operating over packet-switched networks. It aims to bridge the gap between a classical networking class and a classical digital communications class. The course is lab oriented, with a strong emphasis on programming assignments (both C and MATLAB). Topics covered include data compression, error control in networks, and network algorithms. ECE 446 is a culminating design experience (CDE) course.

**ECE 451 Electric Power Systems I**

Fall. 3 credits. Prerequisite: ECE 320 or equivalent. H. Chiang.

The objective is to acquaint the student with modern electric power system analysis and control. Analysis techniques appropriate for the restructured industry and advanced protection and control systems are stressed. Topics include transmission line models, transformers and per unit system, generator models, network matrices, power flow, system protection, computer relaying, and GPS-based measurement and control systems.

**ECE 452 Electric Power Systems II**

Spring. 3 credits. Prerequisite: ECE 451 or permission of instructor. R. J. Thomas.

Acquaints students with modern electric power system operation and control. Aspects of the restructuring of the industry and its implications for planning and operation objectives and methods are explored. Topics include unit commitment, economic dispatch, optimal power flow, control of generation, system security and reliability, state-estimation, analysis of system dynamics, and system protection.

**ECE 453 Analog Integrated Circuit Design**

Fall. 4 credits. Prerequisite: ECE 315 or equivalent. ECE 457 recommended as a corequisite. A. B. Apsel.

Overview of devices available to analog integrated-circuit designers in modern CMOS and BiCMOS processes: resistors, capacitors, MOS transistors, and bipolar transistors. Basic building blocks for linear analog integrated circuits: single-stage amplifiers, current mirrors, and differential pairs. Transistor-level design of linear analog integrated circuits, such as operational amplifiers and operational transconductance amplifiers. Layout techniques for analog integrated circuits. Throughout the course, emphasis is placed on design-oriented analysis techniques. ECE 453 is a culminating design experience (CDE) course.

**ECE 457 Silicon Device Fundamentals**

Fall. 4 credits. Prerequisites: ECE 315 and ECE 306 or MSE 262 or AEP 450. S. Tiwari.

Semiconductor carrier statistics, band diagrams, transport and their applications in diodes, MOSFET, and BJT. Emphasis is put on the CMOS operations for advanced VLSI technology. Six labs cover device measurements and design by simulation. By using the combined simulation and measurement, the course culminates in a comprehensive design project dealing with technical concerns in current VLSI industry as well as its economical, environmental, and social impacts. ECE 457 is a culminating design experience (CDE) course.

**ECE 467 Digital Communication Receiver Design**

Fall. 4 credits. Prerequisite: ECE 220. C. R. Johnson.

An introduction to broadband digital receiver design. Topics include PAM and QAM modulation and down-conversion, pulse-shaping, matched filtering, carrier frequency and phase recovery, baud-timing synchronization, packet marker synchronization, adaptive linear equalization, and coding. Course project: composition and testing of a Matlab-based software receiver. ECE 467 is a culminating design experience (CDE) course.

**ECE 468 Telecommunication Systems**

Spring. 4 credits. Prerequisite: ECE 467 or permission of instructor. Suggested prerequisite: ECE 411. C. R. Johnson.

Fundamentals of digital communications. Topics include: digital source coding, Huffman coding, sampling, quantization, analog source coding; optimum receivers for digital transmission through additive white Gaussian noise (AWGN) channels, matched filters; channel capacity and error control coding; digital transmission through bandlimited AWGN channels, inter-symbol interference (ISI), equalization techniques; phase-locked loops (PLL); trellis-coded modulation (TCM); and spread-spectrum communication systems.

**ECE 472 Feedback Control Systems (also CHEME 472 and M&AE 478)**

Fall, spring. 4 credits. Prerequisite: CHEME 372, ECE 220, M&AE 326, or permission of instructor. Staff.

For description, see M&AE 478.

**ECE 473 Optimizing Compilers**

Fall. 4 credits. Prerequisite: ECE/COM S 314. B. P. Burtscher.

This course provides in-depth coverage of how compilers optimize code for high-performance microprocessors as well as how software interacts with hardware and the operating system. The projects involve implementing, testing, and evaluating an optimizing compiler backend that generates executables for a UNIX workstation. Lecture topics include static single assignment form (SSA), redundancy elimination, loop optimizations, procedure optimizations, register allocation, instruction scheduling, control-flow optimizations, numerous small optimizations, feedback optimizations, executable formats, and system calls.

**ECE 474 Digital VLSI Design**

Fall and spring. 5 credits (fall 4, spring 1). Prerequisites: ENGRD 230, ECE/COM S 314. Students will receive an R grade until they test their chips in the spring. K. T. Kornegay.

Introduction to digital VLSI design. Topics include basic transistor physics, switching networks and transistors, combinational and sequential logic, latches, clocking strategies, domino logic, PLAs, memories, physical design, floor planning, CMOS scaling, and performance and power considerations, etc. Lecture and homework topics emphasize disciplined design, and include: CMOS logic, layout, and timing; computer-aided design and analysis tools; and electrical and performance considerations. Students tape out a small project that is tested in the following semester. The course also includes an introduction to asynchronous design. ECE 474 is a culminating design experience (CDE) course.

**ECE 475 Computer Architecture**

Fall. 4 credits. Prerequisites: ENGRD 230 and ECE or COM S 314. J. F. Martínez.

Topics include instruction set principles, advanced pipelining, data and control hazards, multi-cycle instructions, dynamic scheduling, out-of-order execution, speculation branch prediction, instruction-level parallelism, and high-performance memory hierarchies. Students learn the issues and tradeoffs involved in the design of modern microprocessors. Labs involve the design of a processor and cache subsystem at the RTL level. ECE 475 is a culminating design experience (CDE) course.

**ECE 476 Digital Systems Design Using Microcontrollers**

Spring. 4 credits. Prerequisite: ECE/COM S 314 (ECE 315 strongly recommended). B. R. Land.

Design of real-time digital systems using microprocessor-based embedded controllers.

Students working in pairs design, debug, and construct several small systems that illustrate and employ the techniques of digital system design acquired in previous courses. The content focuses on the laboratory work. The lectures are used primarily for the introduction of examples, description of specific modules to be designed, and instruction in the hardware and high-level design tools to be employed. ECE 476 is a culminating design experience (CDE) course.

**ECE 484 Introduction to Controlled Fusion: Principles and Technology (also M&AE 459 and NS&E 484)**

Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics. Intended for seniors and graduate students in engineering and the physical sciences. Offered alternate years. D. A. Hammer.

For description, see NS&E 484.

**ECE 486 Electromagnetic Waves and Communication**

Spring. 3 credits. Prerequisite: ECE 303. D. L. Hysell.

This course is recommended for students who wish to obtain a greater understanding of the fundamentals of guided waves, high data rate electronics and wireless communication. Topics covered include vector and scalar potentials, transmission lines, waveguides, fiber optics, antenna arrays, and propagation in different environments including interference and diffraction.

**ECE 487 Introduction to Radar and Remote Sensing**

Fall. 3 credits. Prerequisites: ECE 220 and ECE 486 (or a grade of B or better in ECE 303). D. L. Hysell.

Fundamentals of antenna theory, including gain and effective area, near and far fields, phased arrays, and aperture antennas and aperture synthesis. Fundamentals of radar, including detection, tracking, Doppler shifts, sampling, and range and frequency aliasing. Synthetic aperture radars and remote sensing from aircraft and satellites; over-the-horizon (OTH) radars and ionospheric propagation effects; and radar astronomy techniques.

**ECE 488 RF Circuits and Systems**

Spring. 4 credits. Prerequisites: ECE 315 or equivalent. 2 design credits. Lab credit. W. E. Schwartz.

Basic RF circuits and applications. Receivers, transmitters, modulators, filters, detectors, transmission lines, oscillators, frequency synthesizers, low-noise amplifiers. Applications include communication systems, radio and television broadcasting, radar, radio, and radar astronomy. Computer-aided circuit analysis. Five laboratory sessions. ECE 488 is a culminating design experience (CDE) course.

**ECE 491–492 Senior Electrical and Computer Engineering Project**

Fall, 491; spring, 492. 1–8 credits. Limited to seniors in Engineering.

Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor prior to registration for this course and submit a request for an independent project form to the Electrical Engineering undergraduate office.

**ECE 493 Introduction to Evolutionary Computation**

Fall. 3 credits. Prerequisite: a course in probability. D. F. Delchamps.

An introductory course that attempts to address the development of the field and culminates in discussion of current research topics. Specific choices of subject matter and focus will reflect the instructor's interests and will probably include evolutionary game theory and its relationship to learning.

**[ECE 495 Optimizing Compilers**

Fall. 4 credits. Prerequisite: ECE/COM S 314. Not offered 2004–2005. M. Burtscher.

This course provides in-depth coverage of modern compiler optimizations for high-performance microprocessors. Topics include static single assignment form (SSA), redundancy elimination, loop optimizations, procedure optimizations, register allocation, instruction scheduling, control-flow optimizations, interprocedural analysis and optimization, numerous "small" optimizations, and feedback optimizations. The projects involve implementing, testing, and evaluating a number of advanced compiler optimizations for a high-end microprocessor.]

**ECE 496 Principles of Large Scale, Complex Adaptive Networks**

Spring. 4 credits. Prerequisites: ECE requirements through the 200 level, plus some knowledge of probability. Recommended for junior and senior ECE students interested in the systems area. T. L. Fine.

Large-scale complex adaptive (LSCA) networks in ECE include the Internet; World Wide Web; bulk electric power distribution systems; wireless and wired telecommunications networks. We study several principles common to LSCA networks. Each principle will be introduced in the context of a particular large-scale complex adaptive network, abstracted to expose its mathematical essentials, and then illustrated and developed through calculations and/or simulations.

**[ECE 497 Practicum in Analog-Integrated Circuit Design**

Fall and spring (two-semester course). 1 credit. Corequisite: ECE 453. Not offered 2004–2005.

A practicum accompanying ECE 453. During the fall semester, students work in small groups designing an analog-integrated circuit that is sent out for fabrication through MOSIS. When the chips return from fabrication in the spring, students test their designs for functionality and performance.]

**ECE 512 Applied Systems Engineering I (also CEE 504, COM S 504, M&AE 591, OR&IE 512, SYSEN 510)**

Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. A. R. George, R. O. Roundy.

For description, see M&AE 591.

**ECE 513 Applied Systems Engineering II (also CEE 505, COM S 505, M&AE 592, OR&IE 513, SYSEN 520)**

Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 591, or OR&IE 512). Staff.

For description, see M&AE 592.

**ECE 521 Theory of Linear Systems (also M&AE 521)**

Fall. 3 credits. Prerequisite: ECE 320 or permission of instructor. Recommended: a good background in linear algebra and linear differential equations. M. L. Psiaki.

State-space and multi-input-multi-output linear systems in discrete and continuous time. The state transition matrix, the matrix exponential, and the Cayley-Hamilton theorem. Controllability, observability, stability, realization theory. At the level of *Linear Systems* by T. Kailath.

**ECE 526 Signal Representation and Modelling**

Spring. 4 credits. Prerequisites: ECE 425. T. W. Parks.

Sampling and signal reconstruction. Approximation theory. Linear inversion theory. Exponential signal modelling. Multirate filter banks, wavelets, and lifting. Laboratory experiments with speech and image signals.

**ECE 531 Applied Quantum Optics for Photonics and Optoelectronics**

Fall. 4 credits. Prerequisites: ECE 306 and 407, or PHYS 443. F. Rana.

Introduces the basic concepts of quantum optics and quantum electronics necessary for understanding the behavior of optical fields in photonic and optoelectronic devices and systems. Topics include quantization of the electromagnetic field, quantum mechanical properties of photon states, vacuum fluctuations, noise and quantum Langevin equations, matter-photon interactions, phase-sensitive and phase-insensitive optical amplifiers, direct and coherent photon detection, lasers, parametric oscillators, and photonic devices for quantum information processing.

**[ECE 535 Semiconductor Physics**

Fall. 4 credits. Prerequisites: ECE 407 and 457, or permission of instructor. Not offered 2004–2005. S. Tiwari.

Physics of materials and structures useful in semiconductor electronic and photonic devices, including crystal structure, energy bands, effective mass, phonons, classical low-field transport, high-field and ballistic charge carrier transport, electron scattering by phonons, optical absorption, reflection, optical emissions, deep levels as charge carrier traps, and surface and interface effects. On the level of *Compound Semiconductor Device Physics* by S. Tiwari.]

**ECE 536 Nanofabrication for MENG (also ECE 336 and MS&E 541)**

Spring. 3 credits. Prequisites: PHYS 213 or 217, PHYS 214 or 218; CHEM 211 or 207; or equivalent. D. Ast.

For description, see MS&E 541.

**[ECE 547 Computer Vision**

Fall. 4 credits. Prerequisites: ECE 220 (or COM S 280 and 314) or consent of instructor. Not offered 2004–2005.

Computer acquisition and analysis of image data with emphasis on techniques for robot vision. This course concentrates on descriptions of objects at three levels of abstraction: segmented images (images organized into subimages that are likely to correspond to interesting objects), geometric structures (quantitative models of image and world structures), and relational structures (complex symbolic descriptions of images and world structures). The programming of several computer-vision algorithms is required.]

**[ECE 548 Digital Image Processing**

Fall. 4 credits. Prerequisites: ECE 411, ECE 425, familiarity with linear algebra. Not offered 2004–2005.

Introduction to image processing through seven major topics: perception, statistical modeling, transforms, enhancement, analysis, compression, and restoration. Special attention is allocated to compression. Equal emphasis is placed on gaining a mathematical and an intuitive understanding of algorithms through actual image manipulation and viewing.]

**ECE 551 Electric Systems Engineering and Economics (Electricity Markets) (also AEM 655)**

Fall. 2 credits. Prerequisites: basic calculus, microeconomics. R. J. Thomas, T. D. Mount.

This course is designed to explore new arrangements in power system planning and operation brought about by the current restructuring of the electric industry. The course is organized around lectures on 1) how basic economic principles interact with basic engineering principles used to determine the physical and operational makeup of the system; and 2) the principles and techniques of optimization and their applications to emerging institutional arrangements in the power industry. The course involves extensive laboratory work designed to test the principles under discussion. A final project is assigned, requiring building an intelligent software agent capable of performing in a competitive market with rules similar to those being set up in the electric power business today. The agents are exercised in a class competition.

**ECE 554 Advanced Analog VLSI Circuit Design**

Spring. 4 credits. Prerequisite: ECE 453. A. B. Apsel.

Advanced analog integrated circuit and system design. Topics include integrated continuous-time filter design, translinear circuits and systems, dynamic analog techniques, integrated discrete-time filter design, and Nyquist-rate data converter design.

**[ECE 558 Compound Semiconductor Electronics**

Spring. 3 or 4 credits; 4 with a project. Prerequisite: ECE 457 or equivalent. Not offered 2004–2005.

Electronic properties of advanced semiconductor structures using compound semiconductor materials and heterojunctions. Fundamentals of carrier transport and scattering. Properties of direct bandgap semiconductors and quantum wells. Advanced semiconductor devices, including metal-semiconductor transistors (FETs), modulation-doped FETs, and heterojunction bipolar transistors (HBTs). High-frequency operation of compound semiconductor devices. Includes six two-week labs, which include low-temperature carrier transport, optical absorption and emission, and electrical characterization of compound semiconductor devices.]

**[ECE 561 Error Control Codes**

Fall. 4 credits. Prerequisite: ECE 320 or ECE 521 or equivalent. A strong familiarity with linear algebra is assumed. Not offered 2004–2005.

An introduction to the theory and practice of error control codes. Topics include algebraic codes, convolutional codes, concatenated codes, and codes on graphs. The construction and decoding of Reed-Solomon (RS) codes will be considered in some detail, as will the iterative (turbo) decoding of concatenated codes and codes on graphs. The use of error control in wireless systems will be discussed throughout the course.]

**ECE 562 Fundamental Information Theory**

Spring. 4 credits. Prerequisite: ECE 310 or equivalent. T. Berger.

Fundamental results of information theory with application to storage, compression, and transmission of data. Entropy and other information measures. Block and variable-length codes. Channel capacity and rate-distortion functions. Coding theorems and converses for classical and multiterminal configurations. Gaussian sources and channels.

**ECE 563 Communication Networks**

Fall. 4 credits. Prerequisite: ECE 411 or permission of instructor. T. Berger.

Classical line-switched communication networks: point-process models for offered traffic; blocking and queuing analyses. Stability, throughput, and delay of distributed algorithms for packet-switched transmission of data over local-area and wide-area nets. Flow control and capacity assignment algorithms, ATM networks.

**ECE 564 Detection and Estimation**

Spring. 4 credits. Prerequisites: ECE 310, ECE 411, or instructor's consent. L. Tong.

A graduate-level introduction to fundamentals of signal detection and estimation with applications in communications. Elements of decision theory. Sufficient statistics. Signal detection in discrete and continuous time. Multiuser detection. Parameter estimations. Applications in wireless communications.

**ECE 566 Wireless Networks**

Fall. 4 credits. Prerequisites: ECE 445 and ECE 411. Z. Haas.

An introductory course in mobile and wireless networks. The course is targeted mainly at the graduate level but is open to undergraduates as well. The course covers fundamental techniques and protocols in the design and operation of the first, second, and third generation of wireless networks. Examples of related topics include cellular systems, medium access control, control of a mobile session and a mobile call, signaling in mobile networks, mobility management techniques, common air interfaces (AMPS, IS-136, IS-95, GSM), wireless data (CDPD, Mobitex), satellite communication, ad hoc networks (Bluetooth), Internet Mobility, Personal Communication Services (PCS), and so on.

**ECE 567 Digital Communications**

Fall. 4 credits. Prerequisites: ECE 310, ECE 411, or instructor's consent. L. Tong.

A graduate-level introduction to fundamentals of digital communications. Complex random signals. Digital modulations and optimal receiver principles. Baseband and passband transmissions and processing. Interference channels and equalization techniques. Performance analysis including bit error rate calculation and bounds, cutoff rate and channel capacity. Applications in wireless and digital subscriber loops (DSL).

**ECE 568 Mobile Communication Systems**

Spring. 4 credits. Prerequisites: ECE 411 and ECE 467; corequisite: ECE 468. A. Scaglione.

Theory and analysis of mobile communication systems, with an emphasis on understanding the unique characteristics of these systems. Topics include cellular planning, mobile radio propagation and path loss, characterization of multipath and fading channels, modulation and equalization techniques for mobile radio systems, source coding techniques, multiple access alternatives, CDMA system design, and capacity calculations.

**ECE 572 Parallel Computer Architecture (also COM S 516)**

Spring. 4 credits. Prerequisite/corequisite: ECE 475. J. F. Martínez.

Principles and tradeoffs in the design of parallel architectures. Emphasis is on latency, bandwidth, and synchronization in parallel machines. Case studies illustrate the history and techniques of shared-memory, message-passing, dataflow, and data-parallel machines. Additional topics include memory consistency models, cache coherence protocols, and interconnection network topologies. Architectural studies presented through lecture and some research papers.

**ECE 574 Advanced Digital VLSI Design**

Fall. 4 credits. Prerequisites: ECE 474, ECE 475. R. Manohar.

Top-down approach to asynchronous design and the relation between computer architecture and VLSI design. For the asynchronous design component: high-level synthesis, design by program transformations, and correctness by construction. Topics include delay-insensitive design techniques, description of circuits as concurrent programs, circuit compilation, and electrical optimizations. Students complete a group project of the design of a pipelined microprocessor. The processor can be clocked, asynchronous, or a combination of the two. Note: the only difference between taking and not taking ECE 576 is fabricating and testing the chip. All students have to design one.

**ECE 575 High-Performance Processor Architecture**

Spring. 3 credits. Prerequisite: ECE 475. M. Burtscher.

This course provides in-depth coverage of the advanced architectural features of current and next-generation high-performance microprocessors. Topics include superscalar design, out-of-order execution, register renaming, caching, value prediction, confidence estimation, branch prediction, predication, control speculation, multithreading, compiler optimizations, and case studies of existing processors. Projects involve writing simulators to evaluate the performance of various microprocessor components.

**[ECE 576 Advanced Digital VLSI Design Project**

Course starts in spring term and finishes the following fall (2-semester course). 5 credits. Prerequisites: ECE 474, ECE 475. Groups receive an R in ECE 576, for the spring, until they fabricate and test their chips the following fall. Not offered spring and fall 2005.

For description, see ECE 574.]

**[ECE 579 Radio Frequency (RF) Integrated Circuit Design**

Fall and spring. 6 credits. Prerequisites: ECE 433, ECE 453, and ECE 488. Not offered 2004–2005.

This two semester, 6-credit, course conveys practical knowledge of advanced concepts related to the design radio-frequency (RF) integrated circuits in state-of-the-art silicon germanium (SiGe) technology. Emphasis is on the circuit architecture, design, trade-offs, optimization, and layout of RF integrated circuits for use in wireless applications. Special attention is devoted to the most important challenges facing RF circuit designers today, such as the impact of noise, power distribution, and consumption. Low noise amplifier, voltage-controlled oscillator (VCO), phase-lock loop, and high-performance mixer design are emphasized. The basic transmitter/receiver building blocks are covered, and students learn how to design and assemble them to form single-chip wireless systems.]

**ECE 581 Introduction to Plasma Physics (also A&EP 606)**

Fall. 4 credits. Prerequisite: ECE 303 or equivalent. First-year graduate-level course; open to exceptional seniors.
D. A. Hammer.

Topics covered include plasma state; motion of charged particles in fields; drift-orbit theory; coulomb scattering, collisions; ambipolar diffusion; elementary transport theory; two-fluid and hydromagnetic equations; plasma oscillations and waves, CMA diagram; hydromagnetic stability; and elementary applications to space physics, plasma technology, and controlled fusion.

**[ECE 585 Upper Atmospheric Physics I**

Fall. 4 credits. Prerequisites: Physics through 214 or equivalent, introductory chemistry, ECE 486 or equivalent. Not offered 2004–2005.

The structure and dynamics of the ionosphere and upper atmosphere. Charged particle production, loss, and transport. Coupling to the neutral atmosphere. Ionospheric instabilities. High-latitude currents and plasma convection and its implications for the ionosphere and upper atmosphere.]

**ECE 586 Upper Atmospheric Physics II**

Spring. 4 credits. Prerequisites: ECE 581 and ECE 585. C. E. Seyler.

Topics include solar phenomena, solar wind, and space weather; magnetospheric structure and physical processes; plasma instabilities in the ionosphere and magnetosphere; and magnetic reconnection and the relation to high-latitude phenomena.

**ECE 587 Energy Seminar I (also NS&E 545 and M&AE 545)**

Fall. 1 credit. D. A. Hammer.

Energy resources, their conversion to electricity or mechanical work, and the environmental consequences of the energy cycle are discussed by faculty members from several departments in the university and by outside experts. Examples of topics to be surveyed include: energy resources and economics; coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; and air pollution control.

**ECE 588 Energy Seminar II (also M&AE 546)**

Spring 1 credit. D. A. Hammer.

See description for ECE 587; however, there will be different speakers and/or topics discussed in ECE 588.

**ECE 595 Computational Methods in ECE**

Fall. 4 credits. Prerequisites: MATH 294 and knowledge of programming.
A. W. Bojanczyk.

The course presents computational problems in signal processing, telecommunication, control, and other areas of electrical engineering including those leading to least squares, Fourier, cosine and wavelet transforms, spectral decompositions, nonlinear solvers, and quadratic optimization. Special structure of data is exploited to lower the cost of algorithms. Students design and evaluate software in MATLAB and C/C++.

**ECE 596 VLSI for Optical Interconnects**

Spring. 4 credits. Prerequisites: ECE 315, ECE 453, or permission of instructor.
A. B. Apsel.

This course is a graduate-level introduction to the concepts of optoelectronic interconnects. We will cover high-speed circuit design of transmitters and receivers for chip-to-chip and Ethernet communication channels. Topics include transimpedance amplifiers, data formats, introduction to optical devices, drivers, comparisons to conventional interconnect, and novel receiver architectures.

**ECE 597 Computer Systems Management**

Fall. 3 credits. Prerequisite: one of the following (or equivalent): ECE 475, COM S 414, COM S 501, NCC 509. This participatory seminar can be used for the M.Eng. program. P. G. Jessel.

This course is taught from the perspective of a CIO and targeted at engineering and management students interested in "real-world" systems. It provides an introduction to the technical, management, and organizational issues of computer systems in a corporate environment. Topics include IT strategy development, reengineering, enterprise systems, outsourcing, open systems, the Internet, and security.

**ECE 598 MEMS Precision Frequency Synthesis: Contemporary Topics**

Fall. 3 credits. Prerequisite: ECE 315 or equivalent. ECE 432 or equivalent is recommended. A. Lal.

Integrated clocks with stability approaching that of atomic clocks are studied. Topics include CMOS oscillator noise analysis, mechanical resonators, piezoelectricity, and atomic hyperfine interactions.

**ECE 599 Advanced Topics in GPS**

Fall, spring. 1–3 credits. Prerequisites: ECE/M&AE 415 and permission of instructor.
P. M. Kintner.

Topics include GPS receiver design, GPS signal propogation, and applications of GPS to engineering problems. Students are expected to make an oral presentation.

**[ECE 630 Photonics**

Fall. 3 credits. Not offered 2004–2005.

This course covers the primary advances in the photonic field with emphasis on emerging technologies. Typical topics include novel optical materials, optical MEMS, Photonic Band Gaps and the role of optics in next-generation computers.]

**ECE 662 Network Information Theory**

Fall. 3 credits. Prerequisite: ECE 562.
S. Servetto.

A second course in information theory, focusing on multiterminal aspects, as covered in the textbooks of Yeung and of Csiszar/Koerner.

**[ECE 672 Distributed Systems**

Fall. 3 credits. Prerequisite: ECE 475. Not offered 2004–2005.

Design of distributed systems, with particular emphasis on the field of cluster-based architectures. Students read papers, discuss topics in class, make presentations to the class, and complete a major software design project. Topics include runtime system design, coherence protocols for software distributed shared memory systems, fault-tolerant systems, file access, emerging interconnection networks, process and thread migration, adaptive systems, and cluster-based solutions for web servers and multimedia applications.]

**ECE 681 Advanced Plasma Physics I: Cosmic Plasma Services (also A&EP 681)**

Fall. 3 credits. S-U or letter grade.
R. Lovelace.

For description, see A&EP 681.

**ECE 682 Advanced Plasma Physics (also A&EP 682)**

Spring. 3 credits. Prerequisite: ECE 581.
C. E. Seyler.

Course topics include: Boltzmann and Vlasov equations; dielectric tensor; waves in hot magnetized plasmas; Landau and cyclotron damping; microinstabilities; low-frequency stability; nonlinear phenomena; solitons and nonlinear wave equations; ponderomotive effects and parametric processes; plasma models.

**ECE 691–692 Electrical and Computer Engineering Colloquium**

Fall, 691; spring, 692. 1 credit each term. For students enrolled in the graduate field of Electrical and Computer Engineering.
Staff.

Lectures by staff, graduate students, and visiting authorities. A weekly meeting for the presentation and discussion of important current topics in the field. Reports required.

**ECE 693–694 Master of Engineering Design**

Fall, 693; spring, 694. 1–8 credits. For students enrolled in the M.Eng. (Electrical) degree program.

Uses real engineering situations to present fundamentals of engineering design. Each professor is assigned a section number. To register, see roster for appropriate six-digit course ID numbers.

**ECE 695 Statistical Learning Theory**

Fall. 2 credits. Primarily for Ph.D. students. Requires some background in probability and foundations of computer science.
S. Ben-David.

This course focuses on the statistical aspects of automated learning. We wish to understand the issue of automated extraction of regularities (or patterns, or structure) from randomly generated data. This is an informal topics course aiming to demonstrate the type of questions that this research is dealing with as well as some of the tools it can offer.

**ECE 696 Topics in Communications**

Spring. 3 credits. Prerequisite: ECE 562.
Staff.

Introduction to multi-user problems in information theory (such as multiple access and broadcast channels, distributed correlated sources, coding with side information, multiple descriptions), and to classical networking problems (such as routing, flow control, delay, performance of protocols).

Emphasis is on developing tools needed to do research work in this area.

**[ECE 697 Topics in Computer Systems**
Spring. 1 credit. S-U only. Prerequisites: ECE 475 and interest in computer systems. Not offered 2004–2005.
A course for systems graduate students in which the class reads papers about the design and implementation of computer systems and their components. Influential papers from the past as well as papers describing current research and development efforts are discussed.]

**ECE 698 The Foundations of Probability**
Fall. 3 credits. Prerequisite: prior course in probability. T. L. Fine.
This course examines a variety of interpretations/meanings that have been proposed for probability, including logical/epistemic, subjective, frequentist, and propensity. It also examines a variety of mathematical formulations of probability in which probability is not just an assignment of real numbers to events. Examples include comparative probability, interval-valued probability, set-valued probability, and plausibility measures.

**ECE 791–792 Thesis Research**
Fall, 791; spring, 792. 1–15 credits. For students enrolled in the master's or doctoral program.

## INFORMATION SCIENCE, SYSTEMS, AND TECHNOLOGY

W. Arms and C. Cardie, co-directors; G. Bailey, A. Berndt, R. Caruana, M. Eisner, E. Friedman, J. Gehrke, J. Halpern, S. Henderson, D. Huttenlocher, P. Jackson, T. Joachims, J. Kleinberg, L. Lee, J. Muckstadt, S. Resnick, P. Rusmevichientong, B. Selman, J. Shanmugasundaram, D. Shmoys, E. Tardos, M. Todd, L. Trotter, C. Van Loan, D. Williamson

For complete descriptions, see the INFO listing in the CIS section.

**INFO 130 Introductory Design and Programming for the Web (also COM S 130)**
Fall. 3 credits.

**INFO 214 Cognitive Psychology (also COGST 214, PSYCH 214)**
Fall. 3 credits. Sophomore standing required. Limited to 175 students. Graduate students: see INFO 614, PSYCH 614, or COGST 501.

**INFO 230 Intermediate Design and Programming for the Web (also COM S 230)**
Spring. 3 credits. Prerequisite: COM S/INFO 130 or equivalent.

**INFO 245 Psychology and Social Computing (also COMM 245)**
Fall. 3 credits.

**INFO 292 Inventing an Information Society (also ECE 298, ENGRG 298, HIST 292, S&TS 292)**
Spring. 3 credits.

**INFO 295 Mathematical Models for Information Science**
Fall. 4 credits. Corequisite: MATH 231 or equivalent.

**INFO 330 Applied Database Systems (also COM S 330)**
Fall. 3 credits. Prerequisite: COM S 211/ENGRD 211.

**INFO 345 Human-Computer Interaction Design (also COMM 345)**
Spring. 3 credits.

**INFO 349 Media Technologies (also S&TS 349)**
Spring. 3 credits.

**INFO 355 Computers: From Babbage to Gates (also S&TS 355)**
Spring. 4 credits.

**[INFO 387 The Automatic Lifestyle: Consumer Culture and Technology (also S&TS 387)**
Spring. 4 credits. Not offered spring 2005.]

**INFO 430 Information Retrieval (also COM S 430)**
Fall. 3 credits. Prerequisite: COM S 211/ENGRD 211 or equivalent.

**INFO 431 Web Information Systems (also COM S 431)**
Spring. 3 credits. Prerequisites: COM S 211 and some familiarity with the technology of web sites.

**INFO 435 Seminar on Applications of Information Science (also INFO 635)**
Spring. 3 credits. Prerequisites: background in computing, data structures, and programming at the level of COM S 211 or equivalent, and experience in using information systems.

**INFO 440 Advanced Human-Computer Interaction Design (also COMM 440)**
Fall. 3 credits.

**INFO 447 Social and Economic Data (also ILR 447)**
Spring. 4 credits. Prerequisites: one semester of calculus, the IS statistics requirement, at least one upper-level social science course, or permission of the instructor.

**INFO 450 Language and Technology (also COMM 450)**
Spring. 3 credits.

**INFO 490 Independent Reading and Research**
Fall, spring. 1–4 credits.

**INFO 491 Teaching in Information Science, Systems, and Technology**
Fall, spring. Variable credit.

**INFO 515 Culture, Law, and Politics of the Internet**
Fall. 4 credits.

**INFO 530 The Architecture of Large-Scale Information Systems (also COM S 530)**
Spring. 4 credits. Prerequisite: COM S/INFO 330 or COM S 432.

**INFO 614 Cognitive Psychology (also PSYCH 614)**
Fall. 5 credits. S. Edelman.
This course consists of two components: PSYCH 214 (3 credits) and COGST 501 (2 credits). It is intended for graduate students; undergraduates opting for 5 credits should enroll simultaneously in PSYCH 214 and COGST 501.

**INFO 630 Representing and Accessing Digital Information (also COM S 630)**
Fall. 4 credits. Prerequisite: COM S 472 or 478 or 578 or the equivalent.

**INFO 634 Information Technology in Sociocultural Context (also S&TS 634)**
Fall. 4 credits. Prerequisite: permission of instructor.

**INFO 635 Seminar on Applications of Information Science (also INFO 435)**
Spring. 3 credits. Prerequisites: background in computing, data structures, and programming at the level of COM S 211 or equivalent, and experience in using information systems.
Undergraduates and master's students should register for INFO 435. PhD students should register for INFO 635.

**INFO 640 Human-Computer Interaction Design (also COMM 640)**
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.

**INFO 685 The Structure of Information Networks (also COM S 685)**
Spring. 4 credits. Prerequisite: COM S 482.

## MATERIALS SCIENCE AND ENGINEERING

E. P. Giannelis, director; D. G. Ast, S. P. Baker, J. M. Blakely, R. Dieckmann, D. T. Grubb, C. Liddell, G. G. Malliaras, C. K. Ober, A. L. Ruoff, S. L. Sass, M. O. Thompson, C. C. Umbach, R. B. van Dover, U. B. Wiesner

### Undergraduate Courses

**MS&E 111 Nanotechnology (also ENGRI 111)**
Fall. 3 credits. E. Giannelis.
This is a course in the Introduction to Engineering series. For description, see ENGRI 111.

**MS&E 118 Design Integration: A Portable CD Player (also ENGRI 118 and T&AM 118)**
Spring. 3 credits. W. Sachse.
This is a course in the Introduction to Engineering series. For description, see ENGRI 118.

**MS&E 119 Biomaterials for the Skeletal Systems (also ENGRI 119)**
Fall. 3 credits. D. T. Grubb.
This is a course in the Introduction to Engineering series. For description, see ENGRI 119.

**MS&E 124 Designing Materials for the Computer (also ENGRI 124)**
Spring. 3 credits. 3 lectures.
This is a course in the Introduction to Engineering series. For description, see ENGRI 124.

**MS&E 204 Materials Chemistry**
Spring. 4 credits. U. Wiesner.
This course is designed to give a molecular understanding of materials properties with emphasis on general concepts. In the first part, the structure of atoms is discussed introducing fundamental concepts of quantum chemistry. In the second part the transition from atoms to molecules is made discussing symmetry aspects of chemical bonding.

The last part describes the transition from molecules to materials. Materials classes covered include modern examples of polymers, organic semiconductors, ceramics, organic-inorganic hybrids, and superconductors emphasizing the interdisciplinary nature of materials science. Examples illustrate current materials research involving nano-biotechnology, organic optoelectronics, self-assembling materials, or nano-ceramic.

**MS&E 206 Atomic and Molecular Structure of Matter (also M&AE 313)**
Spring. 4 credits. Staff.
The course discusses the basic elements of structure; order and disorder; ideal gas; crystals; liquids; amorphous materials; polymers; liquid crystals; composites; crystal structure; x-ray diffraction.

**MS&E 261 Mechanical Properties of Materials: From Nanodevices to Superstructures (also ENGRD 261)**
Fall. 3 credits. S. P. Baker.
For description, see ENGRD 261.

**MS&E 262 Electronic Materials for the Information Age (also ENGRD 262)**
Fall. 3 credits. Prerequisite: MATH 192; Corequisite: PHYS 213 or permission of instructor. G. Malliaras.
For description, see ENGRD 262.

**MS&E 291–292 Research Involvement IIa and IIb**
291, fall; 292, spring. 3 credits each term. Prerequisite: approval of department. Staff.
Supervised independent research project in association with faculty members and faculty research groups of the department. Students design experiments, set up the necessary equipment, and evaluate the results. Creativity and synthesis are emphasized. Each semester may be taken as a continuation of a previous project or as a one-term affiliation with a research group.

**MS&E 302 Mechanical Properties of Materials, Processing, and Design (also M&AE 323 and MS&E 582)**
Spring. 4 credits. Prerequisite: MS&E 206. Corequisite: MS&E 304 or permission of instructor. S. P. Baker.
Stress and infinitesimal strain as second-rank Cartesian tensors. Linear elasticity and fourth-rank Cartesian tensors. Symmetry effects (Nye, *Physical Properties of Crystals*). Design criteria for beams, shafts, and pressure vessels (Dowling, *Mechanical Behavior of Materials*). Generalized plastic flow relations. Design based on yielding, fracture toughness, fatigue, creep, and rupture with specific applications. Basis for improved materials.

**MS&E 303 Thermodynamics of Condensed Systems**
Fall. 4 credits. Prerequisites: PHYS 214 and MATH 294. M. O. Thompson.
The three laws of thermodynamics are introduced as the fundamental basis for thermal and chemical equilibrium, coupled with statistical mechanical interpretations for entropy and specific heat capacities. These principles are applied to understanding phase equilibria and phase diagrams, heterogeneous reactions, solutions, surfaces, and defects. Introduction to electrochemistry and fuel/power cells.

**MS&E 304 Kinetics, Diffusion, and Phase Transformation (also MS&E 584)**
Spring. 4 credits. Prerequisite: MS&E 303 or permission of instructor.
The topics covered include phenomenological and atomistic theories of diffusion; diffusion in metals, alloys, and nonmetals, including polymers; diffusion in the presence of driving forces; fast diffusion paths; thermo- and electrotransport; interfaces and microstructure; nucleation and growth; growth of product layers (parabolic and linear kinetics); solidification of alloys; diffusional and diffusionless transformations in solids; glass transition.

**MSE 305 Electronic, Magnetic and Dielectric Properties of Materials (also MS&E 585)**
Fall. 4 credits. Prerequisite: MS&E 206 or permission of instructor. R. B. van Dover.
Electronic structure of materials and connection to transport, magnetic, and dielectric properties. Wave and particle nature of electrons, wave packets, potential wells, barriers, tunneling. Valence electron behavior in crystals, density of states for metals, Fermi level, field and thermionic emission, Schottky barriers. Periodic potentials and band structure of crystals. Intrinsic and doped semiconductors, junction electronic and optical devices. Physical origin of magnetic behavior, ferromagnetic domains, magneto-resistance. Materials for data storage and manipulation. Polarization in dielectric materials; frequency dependence of dielectric constants and refractive indices. Ferroelectric domains. Dielectric components in devices. The close connection between fundamental concepts and current technology will be emphasized.

**MS&E 307 Materials Design Concept I**
Fall. 2 credits. S. Sass.
For description, see MS&E 407.

**MS&E 311 Junior Laboratory I**
Fall. 1 credit. Staff.
Practical laboratory covering the analysis and characterization of materials and processing. The fall semester labs will be based on materials from courses in thermodynamics of condensed systems and electronic, magnetic, and dielectric properties of materials.

**MS&E 312 Junior Laboratory II**
Spring. 1 credit. Staff.
Practical laboratory covering the analysis and characterization of materials and processing. The spring semester labs will be based on course material in kinetics, diffusion, and phase transformation and mechanical properties of materials, processing, and design.

**MS&E 391–392 Research Involvement IIIa and IIIb**
391, fall; 392, spring. 3 credits each term. Prerequisite: approval of department. Staff.
For description, see MS&E 291. May be continuation or a 1-term affiliation with a research group.

**MS&E 403–404 Senior Materials Laboratory I and II**
403, fall, 3 credits; 404, spring, 2 credits. D. Grubb.
Practical laboratory covering the analysis and characterization of materials and processing. Emphasis is on design of experiments for evaluation of materials' properties and performance as related to processing history and microstructure. Projects available in areas such as plasticity, mechanical and chemical processing, phase transformations, electrical properties, magnetic properties, and electron microscopy.

**MS&E 405–406 Senior Thesis I and II**
405, fall; 406 spring. 4 credits each term. Staff.
Open to advanced undergraduates in lieu of the senior materials laboratory. Proposals for thesis topics should be approved by the supervising faculty member prior to beginning the senior year. Approved thesis topics normally involve original experimental research in direct collaboration with an ongoing research program. Periodic oral and written presentations and a final written thesis are required. Both semesters must be taken to complete the laboratory requirement. This course is required for graduation with honors.

**MS&E 407 Materials Design Concepts II**
Fall. 2 credits. S. Sass.
The goal of this course is to introduce materials design in the context of real world materials design projects carried out in industry. In the first portion of the course, the process of engineering design will be studied in light of economic, environmental, regulatory, and safety issues. Patent searching and communication skills will be addressed. In the second portion of the course, speakers from industry lecture on case studies of materials design problems. Students give oral presentations and write technical reports based on the case studies.

**MS&E 433 Materials for Energy Production, Storage, and Conversion**
Fall. 3 credits. R. Dieckmann.
This new course is concerned with materials and technologies related to energy production, storage, and conversion as well as to sensors used for monitoring the emission of pollutants. The devices discussed include solar cells, fuel cells, batteries, and electrochemical sensors. Thermodynamic, kinetic, and electrochemical concepts and materials properties critical for such devices will be the central part of this class.

**MS&E 461 Biomedical Materials and Their Applications**
Spring. 3 credits. D. Grubb.
Many types of materials are used in biomedical engineering to replace or supplement natural biological systems. Interaction with blood and tissues is always of primary importance, but depending on the use of the biomedical material, mechanical, optical, and transport properties also may be vital. After a general introduction to biomedical materials, much of the course is taken up with case studies where a physiological system is considered, then the design of artificial parts and the materials now chosen are investigated. Constraints such as methods of production, economics, regulatory approval, and legal liabilities are included in the case study. Examples may include dialysis, contact and intra-ocular lenses, heart valves, and the artificial pancreas. Every student is involved in a presentation to the class about a case study.

**MS&E 471 Transmission Electron Microscopy**
Fall. 1 credit. S. Sass.
This course covers the theory and practice of obtaining and interpreting TEM data from crystalline materials. Topics include microscope optics and conventional and high-resolution image formation. Special emphasis is placed on electron diffraction (formation and analysis of spot patterns, Kikuchi pattern, and convergent beam pattern) and obtaining useful images of crystal defects.

Practical requirements for high-resolution imaging of crystal lattices and interfaces also are covered. Associated theoretical topics include kinematical and dynamical diffraction theories, the contrast transfer function theory of phase contrast, and image modeling and image analysis for quantitative interpretation of data. Current text is *Transmission Electron Microscopy* by D. B. Williams and C. B. Carter.

**MS&E 481 Technology Management (also MS&E 587)**
Spring. 3 credits. E. P. Giannelis.
This course is designed to provide students in engineering and the sciences with the knowledge and analytical skills to manage R&D for a strategic competitive advantage. Most organizations recognize the critical importance of R&D management in becoming and remaining world-class competitors. The course uses a combination of case studies, readings, discussions, and outside lectures. Topics include technology evaluation, R&D portfolio, intellectual property portfolio and management, technology transfer, and technology, policy, and society.

**MS&E 487 Ethics and Technology**
Fall. 1 credit. C. Ober.
Ethics influences all decisions made by a technologist. This course discusses those factors that must be considered in reaching a decision involving technology, ranging from legal impact to consideration of community expectations.

**MS&E 491–492 Research Involvement IVa and IVb**
491 fall; 492, spring. 3 credits each term. Prerequisite: approval of department. Staff.
For description, see MS&E 291. May be continuation or a one-term affiliation with a research group.

**MS&E 495 Undergraduate Teaching Involvement**
Fall, spring. Variable credit. Staff.
This course will give credit to students who help in the laboratory portions of select MS&E courses. The number of credits earned will be determined by the teaching load and will typically be 1–3 credits.

**MS&E 512 Mechanical Properties of Thin Films (also M&AE 513)**
Spring. 3 credits. Offered alternate years. S. P. Baker.

**MS&E 521 Properties of Solid Polymers**
Fall. 3 credits. Prerequisite: ENGRD 261. Corequisite: MS&E 303 or permission of instructor. C. K. Ober.
Synthetic and natural polymers for engineering applications. Production and characterization of long-chain molecules. Thermodynamics of polymer mixtures. Polymer molecular weight. Gelation and networks, rubber elasticity, elastomers, and thermosetting resins. Amorphous and crystalline thermoplastics and their structure. Time- and temperature-dependent elastic properties of polymers. Glass transition and secondary relaxations. Plastic deformation and molecular orientation.

**MS&E 523 Physics of Soft Materials**
Fall. 3 credits. Offered alternate years. U. B. Wiesner.
The course covers general aspects of structure, order, and dynamics of soft materials. Typical representatives of this class of materials are polymers, liquid crystals, gels, and surfactant solutions. A general formalism for the description of order in terms of orientation distribution functions is introduced. Examples are given for the measurement of order parameters for partially ordered materials. Finally, the dynamics of soft materials is discussed. Besides transport and flow behavior aspects of the local dynamics of soft materials are presented. Emphasis is put on the discussion of various techniques frequently used (and available at Cornell) for the characterization of structure, order and dynamics of soft materials such as NMR or various scattering techniques. Using examples of modern multidimensional spectroscopic methods the issue of heterogeneous dynamics at the glass transition of amorphous liquids is presented at the end of the class.

**[MS&E 524 Materials Chemistry of Synthetic Polymeric Materials**
Fall. 3 credits. Prerequisite: MS&E 521 or permission of instructor. Offered alternate years.]

**[MS&E 525 Organic Optoelectronics**
Fall. 3 credits. Offered alternate years. G. G. Malliaras.]

**MS&E 531 Introduction to Ceramics**
Spring. 3 credits. C. Liddell.
This course covers ceramic processes and products, structure of ceramic crystals, structure of glasses, structural defects (point defects, dislocations), surfaces, interfaces and grain boundaries, diffusion in ionic materials (atomistic and phenomenological approach, relationships between diffusion and point defect structure), ceramic phase diagrams, phase transformations. Physico-chemical aspects of the different topics are emphasized.

**MS&E 541 Nanofabrication**
Spring. 3, 4, or 5 credits. D. Ast.
The previous material science course in microprocessing has been combined with ECE 336 and is taught jointly with ECE. The course consists of a 2-lecture, 3-credit core course providing an introduction to the materials and processes used to fabricate integrated circuits and micro electromechanical systems. An optional extension is a hands-on, 1-credit, laboratory in which students fabricate transistors, simple integrated circuits, and MEMS structures. Students enrolled in MS&E 541 must enroll in the advanced topic, 1-credit section of the course. Enrollment in the advance credit section is optional for students registered in ECE 336. The recommended textbook is *The Science and Engineering of Microelectronic Fabrication* by Campbell. Course notes available to registered students on a password-protected web site.

**[MS&E 542 Materials Design in Electronic Packaging**
Spring. 3 credits. Not offered 2004–2005. Staff.]

**MS&E 543 Thin-Film Material Science**
Fall. 3 credits. Offered alternate years. D. G. Ast.
This course provides fundamental information on the deposition, properties, reaction, and evaluation of thin films. Topics covered include: deposition techniques, surface energies, stress in thin films, surface kinetics, homoepitaxy, heteroepitaxy and superlattices, electrical and optical properties, Schottky barriers, solid phase regrowth, interdiffusion, thin film reactions, and electromigration. The recommended textbook is *Electronic Thin Film Science for Electrical Engineers and Material Scientists* by Tu, Mayer, and Feldman.

**MS&E 544 Plasma Processing of Electronic Materials (also ECE 482)**
Spring. 3 credits. Prerequisites: PHYS 213 and 214 or equivalent. Offered on demand. Staff.
For description, see ECE 482.

**MS&E 545 Magnetic and Ferroelectric Materials**
Fall. 3 credits. Prerequisites: PHYS 213 and 214 or equivalent. Offered alternate years. R. B. van Dover.
This course covers the fundamentals of magnetic phenomena and specific magnetic materials and their use in modern applications. Magnetization phenomena, the origin of magnetism in a material, magnetic domains, and magnetic anisotropy are included in the fundamentals. Specific magnetic materials and their applications include ferromagnetism in thin films and fine particles, amorphous magnetic materials; magnetic recording, magnetic circuits.

**[MS&E 546 Solar Cells: Energy from the Environment**
Fall. 2 or 3 credits. Lec, 2 credits. Lab, 1 credit. Laboratory enrollment is limited to 10 students. No prerequisites. Not offered fall 2004. D. G. Ast.]

**MS&E 555 Introduction to Composite Materials (also CEE 475, M&AE 455, and T&AM 455)**
Spring. 3 credits.
For description, see T&AM 455.

**MS&E 563 Nanobiotechnology (also A&EP 663 and BIO G 663)**
Spring. 3 credits.
For description, see A&EP 663.

**[MS&E 571 Analytical Techniques for Material Science (Also MS&E 603)**
Spring. 3 credits. Offered alternate years. Not offered spring 2005.]

**[MS&E 572 Computational Materials Science**
Spring. 3 credits. Prerequisite: MS&E 303/601 or equivalent; programming. Not offered spring 2005. M. O. Thompson.]

## Graduate Professional Courses

**MS&E 501–502 Special Project**
501, fall; 502, spring. 6 credits each term.
Master of Engineering research project.

**MS&E 581 Atomic and Molecular Structure of Matter (also MS&E 206 and M&AE 313)**
Spring. 4 credits. Staff.
For description, see MS&E 206.

**MS&E 582 Mechanical Properties of Materials, Processing, and Design (also MS&E 302 and M&AE 323)**
Spring. 4 credits. Corequisite: MS&E 584 or permission of instructor.
For description, see MS&E 302.

**MS&E 583 Thermodynamics of Condensed Systems (also MS&E 303)**
Fall. 4 credits. M. O. Thompson.
For description, see MS&E 303.

**MS&E 584 Kinetics, Diffusion, and Phase Transformation (also MS&E 304)**
Spring. 4 credits. Prerequisite: MS&E 583 or permission of instructor.
For description, see MS&E 304.

**MS&E 585 Electronic, Magnetic, and Dielectric Properties of Materials (also MS&E 305)**
Fall. 4 credits. R. B. van Dover.
For description, see MS&E 305.

**MS&E 587 Technology Management**
Spring. 3 credits. E. P. Giannelis.
For description, see MS&E 481.

## Graduate Core Courses

**MS&E 601 Thermodynamics of Materials**
Fall. 3 credits. Prerequisite: course in thermodynamics at level of MS&E 303. J. M. Blakely.
Topics covered include basic statistical thermodynamics, partition functions and thermodynamic state functions, distributions, laws of thermodynamics, free-energy functions and conditions of equilibrium, chemical reactions, statistics of electrons in crystals, heat capacity, heterogeneous systems and phase transitions, and lattice models of 1-, 2-, and 3-dimensional interacting systems. Also covers: statistical thermodynamics of alloys, free-energy and phase diagrams, order-disorder phenomena, point defects in crystals, and statistical thermodynamics of interfaces.

**[MS&E 602 Elasticity, Plasticity, and Fracture**
Spring. 3 credits. Offered alternate years. Not offered spring 2005.]

**[MS&E 603 Analytical Techniques for Materials Science (also MS&E 571)**
Spring. 3 credits. Offered alternate years. Not offered spring 2005.
For description, see MS&E 571.]

**MS&E 604 Kinetics of Reactions in Condensed Matter**
Spring. 3 credits. A. L. Ruoff.
Phenomenology and microscopic aspects of diffusion in fluids, both simple and polymeric, and in metallic, ionic, semiconductor, and polymeric solids. Cartesian tensors are utilized for fields and properties. Covers phase stability and transformations; nucleation and growth, spinodal decomposition and displacive transformations; phase coarsening processes, recrystallization, and grain growth; diffusion-controlled growth, interfacial reactions, moving boundary problems; grain-boundary migration controlled kinetics; viscosity, anelasticity, and diffusional creep. Texts: 1) Shewmon, *Diffusion in Solids*, 2) Porter and Easterling, *Phase Transformations in Metals and Alloys*.

## Related Course in Another Department

Introductory Solid-State Physics (PHYS 454)

## Further Graduate Courses

**MS&E 621 Advanced Inorganic Chemistry III: Solid-State Chemistry (also CHEM 607)**
Fall. 4 credits. Prerequisite: CHEM 605 or permission of instructor. S. Lee.
For description, see CHEM 607.

**MS&E 622 Synthetic Polymer Chemistry (also CHEME 675 and CHEM 671)**
Spring. 4 credits. Prerequisites: CHEM 359–360 or equivalent or permission of instructor. Staff.
For description, see CHEM 671.

**[MS&E 631 Solid-State Reactions**
Fall. 3 credits. Offered alternate years. Not offered 2004–2005. R. Dieckmann.]

**[MS&E 632 Solid State Electrochemistry**
Fall. 3 credits. Prerequisite: MS&E 631 or permission of instructor. Not offered 2004–2005. R. Dieckmann.]

**MS&E 655 Composite Materials (also M&AE 655 and T&AM 655)**
Spring. 4 credits. Staff.
For description, see T&AM 655.

**MS&E 665 Principles of Tissue Engineering (also M&AE 665, BMEP 665)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.
This course covers introductory concepts in tissue engineering, including: polymeric biomaterials used for scaffolds, mechanisms of cell-biomaterial interaction, biocompatibility and foreign body response, cell engineering, and tissue biomechanics. This knowledge is applied to engineering of several body systems, including the musculoskeletal system, cardiovascular tissues, nervous system, and artificial organs. These topics are discussed in the context of scale-up, manufacturing, and regulatory issues.

**MS&E 671 Principles of Diffraction (also A&EP 711)**
Spring. 3 credits. Letter grades only. J. D. Brock.
For description, see A&EP 711.

**MS&E 672 Transmission Electron Microscopy (also MS&E 471)**
Fall. 1 credit. Prerequisite: MS&E 206 or equivalent. Offered alternate years.

**MS&E 681 Surfaces and Interfaces in Materials**
Spring. 3 credits. Offered alternate years. J. Blakely.
This course deals with special topics in the field of surface and interface science. Some knowledge of basic statistical thermodynamics, crystallography, elementary quantum mechanics, and theory of rate processes is assumed. The following are the main topics: statistical thermodynamics of interfaces, morphological stability, atomic structure, energetics and structure determination, electronic structure of interfaces, charge and potential distributions, surface steps, adsorption and segregation, atomic transport and growth processes at surfaces, oxidation, and other surface reactions.

## Specialty Courses

**MS&E 800 Research in Materials Science**
Fall, spring. Credit to be arranged. Staff.
Independent research in materials science under the guidance of a member of the staff.

**MS&E 801 Materials Science and Engineering Colloquium**
Fall and spring. 1 credit each term. Credit limited to graduate students. Staff.
Lectures by visiting scientists, Cornell staff members, and graduate students on subjects of interest in materials sciences, especially in connection with new research.

**MS&E 802 Materials Science Research Seminars**
Fall, spring. 2 credits each term. For graduate students involved in research projects. Staff.
Short presentations on research in progress by students and staff.

# MECHANICAL AND AEROSPACE ENGINEERING

S. Leibovich, director; P. L. Auer, C. T. Avedisian, D. L. Bartel, L. J. Bonassar, J. F. Booker, J. R. Callister, M. E. Campbell, D. A. Caughey, L. R. Collins, R. D'Andrea, P. R. Dawson, P. C. T. deBoer, E. M. Fisher, E. Garcia, A. R. George, F. C. Gouldin, C. Hui, H. Lipson, M. Y. Louge, J. L. Lumley, M. P. Miller, F. C. Moon, F. K. Moore, S. Mukherjee, R. M. Phelan, S. L. Phoenix, S. B. Pope, M. L. Psiaki, E. L. Resler, Jr., A. Ruina, W. Sachse, S. E. Shen, K. E. Torrance, F. Valero-Cuevas, M. C. H. van der Meulen, H. B. Voelcker, K. K. Wang, Z. Warhaft, C. H. K. Williamson, N. Zabaras, A. Zehnder

## General and Required Courses

**M&AE 101 Naval Ship Systems (also NAV S 202)**
Spring. 3 credits.
For description, see NAV S 202.

**M&AE 117 Introduction to Mechanical Engineering (also ENGRI 117)**
Fall. 3 credits. 2 lectures and 1 lab per week.
This is a course in the Introduction to Engineering series. For description, see ENGRI 117.

**M&AE 127 Introduction to Entrepreneurship and Enterprise Engineering (also ENGRI 127)**
Spring. 3 credits. Open to all Cornell students regardless of major. No prerequisites.
For description, see ENGRI 127.

**M&AE 212 Mechanical Properties and Selection of Engineering Materials.**
Spring. 3 credits. Prerequisite: ENGRD 202 (strictly enforced). Software fee.
This course covers the mechanics of deformable bodies and reinforces the concept of "simple engineering elements" for mechanical analysis associated with design. There is an introduction to the broad range of properties and behaviors of engineering materials as they relate to mechanical performance. Emphasis is placed on general states of stress and strain and on elasticity and combined loading effects. Failure criteria, including yielding, buckling, fracture, fatigue, and environmental effects, are developed. A general introduction to the function/constraints/objectives approach to material selection associated with mechanical design is provided with candidate material systems coming from metals, polymers, ceramics, and/or composites. A general overview of material processing is presented within this context of material selection.

**M&AE 221 Thermodynamics (also ENGRD 221)**
Fall, spring, may be offered summer. 3 credits. Prerequisites: MATH 192 and PHYS 112 or permission of instructor.
For description, see ENGRD 221.

**M&AE 225 Mechanical Synthesis**
Spring. 4 credits. Prerequisite: ENGRD 202. Pre- or corequisites: ENGRD 203 and ENGRD 221. Lab fee.
A hands-on introduction to the mechanical design process. Basic prototyping skills developed using machine tools. Mechanical dissection used to demonstrate successful

product design and function. Design projects provide experience from conceptualization through prototype construction and testing. Basic instruction on CAD and technical sketching.

**M&AE 323 Introductory Fluid Mechanics**

Fall. Usually offered in the summer through the Engineering Cooperative Program. 4 credits. Prerequisites: ENGRD 202 and 203 and coregistration in 221, or permission of instructor.

Topics covered include physical properties of fluids, hydrostatics, conservation laws using control volume analysis and using differential analysis, Bernoulli's equation, potential flows, simple viscous flows (solved with Navier-Stokes equations), dimensional analysis, pipe flows, boundary layers, introduction to compressible flow.

**M&AE 324 Heat Transfer**

Spring. Usually offered in the summer through the Engineering Cooperative Program. 3 credits. Prerequisite: M&AE 323 or permission of instructor.

Topics include discussion of steady and unsteady heat conduction: forced and free convection; external and internal flows; radiation heat exchange; and heat exchangers and boiling.

**M&AE 325 Analysis of Mechanical and Aerospace Structures**

Fall. Usually also offered in the summer through the Engineering Cooperative Program. 3 credits. Prerequisites: ENGRD 202 and M&AE 212 (strictly enforced).

This course covers topics in the mechanics of materials applied to the analysis and design of structural components encountered in mechanical, aeronautical, and aerospace systems, including the following: torsion and bending of nonsymmetric or curved members, elastic stability, stress concentration, contact stresses, statically indeterminate structures, bound theorems for collapse of structures, and applications to composite and semi-monocoque structures.

**M&AE 326 System Dynamics**

Spring. May be offered in Engineering Cooperative Program. 4 credits. Prerequisite: MATH 294, ENGRD 203. Junior standing required.

Dynamic behavior of mechanical systems: modeling, analysis techniques, and applications; vibrations of single- and multi-degree-of-freedom systems; feedback control systems. Computer simulation and experimental studies of vibration and control systems.

**M&AE 327 Mechanical Property and Performance Laboratory**

Spring. 2 credits. Prerequisites: M&AE 212 and M&AE 325.

This course provides an introduction to the experimental methods, instrumentation, and data analyses associated with material property determination and mechanical performance of materials. Emphasis is placed on integration of theory and analysis with experimental methods.

**M&AE 427 Fluids/Heat Transfer Laboratory**

Fall. 3 credits. Prerequisites: M&AE 323, 324. Fulfills the technical writing requirement.

Laboratory exercises in fluid mechanics and the thermal sciences. Measurements of flame temperature, pressure, heat transfer, viscosity, lift and drag, fluid-flow rate, effects of turbulence, air foil stall, flow visualization, and spark ignition engine performance. Instrumentation, techniques and analysis, and interpretation of results. Biweekly written assignments with extensive feedback.

**M&AE 428 Seminar on Engineering Design**

Fall. 2 credits. Prerequisite: completion of 6 semesters in mechanical engineering or equivalent. S-U grades only.

This course is offered to illustrate the design "process" in action. It consists of formal lectures and invited seminars by industrial and academic practitioners of design. Case studies are presented in weekly invited lectures from a wide range of disciplines, including thermo-fluid processes, manufacturing, energy, mechanical design, aerospace, and biological sciences. The invited lectures are supplemented by one or more design "projects" in the semester.

**M&AE 591 Applied Systems Engineering (also CEE 504, COM S 504, ECE 512, OR&IE 512, SYSEN 510)**

Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor.

For description see SYSEN 510.

**M&AE 592 System Architecture, Behavior, and Optimization (also CEE 505, COM S 505, ECE 513, OR&IE 513, SYSEN 510)**

Spring. 3 credits. Prerequisites: senior/graduate standing and completion of Applied Systems Engineering (CEE 504, COM S 504, ECE 512, M&AE 591, or OR&IE 512, SYSEN 510) or permission of instructor.

See SYSEN 510 for description.

## Mechanical Systems, Design, Materials Processing, and Precision Engineering

**M&AE 103 Introduction to Computer-Aided Manufacture (CAM)**

Fall, spring. 1 credit, approximately eight weeks (total 15 hrs. of instruction and 15 hrs. of lab). Prerequisites: M&AE 225 or equivalent experience and completion of the Emerson Lab Product Realization Facility's CNC seminars: An Introduction to CNC Machining and CNC Programming; or permission of instructor. Limited enrollment.

Completes the introduction to the fundamentals of computer-aided manufacture (CAM) seminars through the use of computer numerical control (CNC) programming. The course is the hands-on component of the three-part series on CAM. Provides practical applications of the use of G codes and solid modeling software, CNC mill and/or lathe setup, tool selection, and operation. The course is required for students wishing to use the CNC equipment in the Emerson Lab's Product Realization Facility for team or research projects. May not be used to fulfill any M&AE requirement.

**M&AE 312 Mechanical Properties of Materials, Processing, and Design (also MS&E 302 and MS&E 582)**

Spring. 4 credits. Prerequisite: MS&E 206. Corequisite: MS&E 304 or permission of instructor.

For description, see MS&E 302.

**M&AE 313 Atomic and Molecular Structure of Matter (also MS&E 206)**

Spring. 4 credits.

For description, see MS&E 206.

**M&AE 378 Mechatronics**

Fall. 4 credits. Prerequisite: MATH 294 (Engineering Mathematics II), PHYS 213 (Physics II: Heat/Electromagnetism), or permission of instructor.

At the intersection of mechanical and electrical engineering, mechatronics involves technologies necessary to create automated systems. It introduces students to the functional elements of modern controlled dynamic systems. Topics include analog circuits (both passive and active components); filter design; transistors; diodes; MOSFETs and power amplification; transduction mechanical and electro-mechanical devices such as electromagnetic systems; piezoelectric and shape memory material transduction; gear trains; pulse width modulation; optical encoders; discretization; aliasing; and microprocessors and programming. Laboratory experiments culminate in the design and programming of a microprocessor-controlled robotic vehicle.

**M&AE 386 Automotive Engineering**

Spring. 3 credits. Prerequisite: M&AE 325 or permission of instructor.

Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis on automobiles. Engines, transmissions, suspension, brakes, and aerodynamics will be discussed. The course uses first principles and applies them to specific systems. The course is highly quantitative, using empirical and analytical approaches. Co-meets with M&AE 486.

**[M&AE 409 Data Structures and Algorithms for Computational Science (also CIS 409)**

Fall. 4 credits. Prerequisite: COM S 100 or programming experience in any language. Not offered every year. Not offered 2004–2005.

For description, see CIS 409.]

**[M&AE 412 Smash and Crash: Mechanics of Large Deformations**

Fall. 4 credits. Prerequisites: M&AE 212, T&AM 202. Fulfills field design requirement. Not offered 2004–2005.

Severe loading is a defining feature of both materials processing and crash worthiness. Materials are stressed beyond their elastic limits intentionally, resulting in large permanent deformations. In materials processing, the desire is to change a work piece shape to manufacture a component; in crash worthiness, the intent is to absorb a vehicle's energy and to protect its occupants. In this course the fundamentals of plasticity are covered: yielding, flow laws, work hardening. Various solution methods, including bound theorems, are presented. The fundamentals are applied to a number of topics in materials processing and crash design. The laboratory experience deals with these topics, culminating with the team design, construction, and testing of a crash cage.]

**M&AE 415 GPS: Theory and Design (also ECE 415)**

Fall. 4 credits. Prerequisites: a 300-level engineering course with advanced math content such as ECE 303 or M&AE 326.

For description, see ECE 415.

**M&AE 417 Introduction to Robotics: Dynamics, Control, Design**

Spring. 3 credits. Prerequisites: engineering math at the level of 293–294; some course in dynamics on the level of T&AM/ENGRD 203; familiarity with control concepts typical of M&AE 326.

Introductory course in the analysis and control of mechanical manipulators and related robotic machines. Topics include spatial descriptions and transformations, manipulator kinematics and inverse kinematics, differential relationships and static forces, manipulator dynamics, trajectory generation, sensors and actuators, trajectory control, and compliant motion control. Simulation and design using MATLAB and multi-body codes are used.

**M&AE 425 FSAE Automotive Design Project**

Fall, spring. 3 credits for team members or 4 credits for team leaders. Intended for M&AE or ECE juniors and seniors or by arrangement with instructor. Usually 3 credits. Permission of instructor only.

Project course to research, design, build, develop, and compete with a Formula SAE car for intercollegiate competition. Students work in interdisciplinary teams using concurrent engineering and systems engineering principles applied to complex mechanical, electromechanical, and electronic systems.

**M&AE 426 FSAE Auto Design Project (Design Option)**

Fall, spring. 3 or 4 credits. Limited to M&AE seniors; permission of instructor only.

Senior design version of M&AE 425. For description, see M&AE 425.

**M&AE 440 Hybrid Electric Vehicle**

Fall, spring. 3 credits for team members; 4 credits for team leaders. Enrollment limited to a maximum of 4 semesters. Permission of instructor only.

Team work on the design and fabrication of a hybrid vehicle for national competition.

**M&AE 441 Hybrid Electric Vehicle (Design Option)**

Fall, spring. 3 or 4 credits. Limited to M&AE seniors; permission of instructor only.

Senior design version of M&AE 440. For description, see M&AE 440.

**M&AE 455 Introduction to Composite Materials (also CEE 475, MS&E 555, and T&AM 455)**

Spring. 3 credits.

For description, see T&AM 455.

**M&AE 461 Entrepreneurship for Engineers (also ENGRG 461 and OR&IE 452)**

Fall. 3 credits.

This course develops skills necessary to identify, evaluate, and begin new business ventures. Topics include intellectual property, competition, strategy, business plans, technology forecasting, finance and accounting, and sources of capital. A rigorous, quantitative approach is stressed throughout, and students create financial documents and plans, analyze human resource models, and work with sophisticated valuation methods, complicated equity structures, and legal and business documents. As such, this course represents the "red meat" of entrepreneurship, and the soft skills are left for other courses. Course work consists of discussions, assignments, and the preparation and presentation of a complete business plan.

**M&AE 463 Neuromuscular Biomechanics (also BMEP 463)**

Spring. 3 credits. Prerequisites: ENGRD 202 and 203 or permission of instructor. Offered alternate years.

Modeling and simulation of biomechanical systems using mechanics, dynamics, and control principles. Physiology of neurons and muscles introduced and related to the production of force and movement in biological systems. Representation of neuromuscular systems as simultaneous equations. Exploration of the muscular redundancy problem using optimization methods and general-purpose languages (such as *Mathematica* or MATLAB). Selected clinical applications.

**[M&AE 464 Orthopaedic Tissue Mechanics**

Spring. 3 credits. Prerequisites: ENGRD 202 and M&AE 325 or permission of instructor. Offered alternate years. Not offered 2004–2005.

Applications of mechanics and materials principles to orthopaedic tissues. Physiology of bone, cartilage, ligament, and tendon introduced and related to mechanical function. Mechanical behavior of skeletal tissues in the laboratory. Functional adaptation of these tissues to their mechanical environment. Tissue engineering of replacement structures.]

**M&AE 466 Biomedical Engineering Analysis of Metabolic and Structural Systems (also BMEP 401)**

Fall. 3 credits. Prerequisites: ENGRD 202 and prior course work in basic biology or permission of instructor.

For description, see BMEP 401.

**M&AE 470 Finite Element Analysis for Mechanical and Aerospace Design**

Spring. 3 credits. Prerequisite: senior standing or permission of instructor. Limited enrollment. Evening examinations. Term project. Fulfills senior design requirement for M&AE students.

Introduction to linear finite element static and dynamic analysis for discrete and distributed mechanical and aerospace structures. Prediction of load, deflection, stress, strain, and temperature distributions. Major emphasis on underlying mechanics and numerical methods. Introduction to computational aspects via educational and commercial software (such as *MATLAB* and *ANSYS*). Selected mechanical and aerospace applications. Co-meets with M&AE 570.

**M&AE 477 Engineering Vibrations**

Spring. 3 credits. Prerequisite: M&AE 326 (or co-registration), or permission of instructor.

Lumped element, distributed parameter, and mixed structural vibratory systems are examined. Equations of motion are derived from Newton's law and Lagrange's equations. Eigen analysis, free and forced responses, and frequency/time domain solutions are considered. Vibration absorbers, isolators, and vibration suppression control systems using feedback approaches also are investigated. Co-meets with M&AE 577.

**M&AE 478 Feedback Control Systems (also CHEME 472, ECE 472)**

Fall. 4 credits. Prerequisite: ECE 220 or M&AE 326 or permission of instructor.

Analysis techniques, performance specifications, and analog-feedback-compensation methods for single-input, single-output, linear, time-invariant systems. Laplace transforms and transfer functions are the principal mathematical tools. Design techniques include root-locus and frequency response methods. Includes laboratory that examines modeling and control of representative dynamic processes. Co-meets with M&AE 578.

**M&AE 479 Modeling and Simulation of Mechanical and Aerospace Systems**

Fall. 3 credits. Prerequisite: senior engineering standing or permission of instructor. Evening examinations. Term project. Fulfills M&AE senior design elective. Limited enrollment. F. Valero-Cuevas.

Analysis and simulation of linear and nonlinear systems. Representation of discrete and distributed dynamical systems by state-variable models. Time- and frequency-domain simulation via general-purpose languages (such as MATLAB or Mathematica) and special-purpose simulation software (such as Simulink). Selected applications from diverse fields. Co-meets with M&AE 579.

**M&AE 486 Automotive Engineering Design**

Spring. 4 credits. Prerequisite: senior standing. Fulfills field senior design requirement for M&AE students.

For description, see M&AE 386.

**[M&AE 513 Mechanical Properties of Thin Films (also MS&E 512)**

Spring. 3 credits. Offered alternate years. Not offered 2004–2005.

For description, see MS&E 512.]

**M&AE 514 Design for Manufacture and Assembly**

Fall or spring. 4 credits. Prerequisites: M&AE 212 or 412, and introductory probability and statistics, or permission of instructor.

Nominal DFMA (design for manufacture and assembly) and variational DFMA are covered in two parallel streams. The nominal stream is based on readings in a popular text that surveys the role of manufacturing and assembly processes in part and product design. The second stream, covered mainly through lectures, addresses dimensional variability and its control through parametric and geometric tolerances, dimensional metrology, and statistical quality and process control.

**M&AE 521 Theory of Linear Systems**

Fall. 3 credits. Prerequisite: M&AE 478/ECE 471/CHEME 472 (may be taken as a co-requisite) or permission of instructor. A strong background in linear algebra and differential equations is required.

Concentrates on the theory of linear dynamic input-output systems. Both continuous-time and discrete-time systems are covered. Topics include state-space realizations of transfer functions, canonical forms, the Cayley-Hamilton theorem, controllability, observability, stability, observers, pole placement, and observer-based controller design. The course concentrates on time-invariant systems, but several topics in time-varying systems also are covered.

**M&AE 525 Advanced Mechatronics-Systems Engineering Project (Robo Cup)**

Fall, spring. 4 credits each term (must be taken for 8 credits). Prerequisite: CHEME 372 or ECE 301 or M&AE 326 or permission of instructor. Fulfills M&AE senior design elective.

Project-based introduction to systems engineering with a focus on system design, systems and technology integration, and systems analysis. Approximately 30 students from the various engineering disciplines design, construct, and fully test several teams of fully autonomous, mobile robots. These teams engage in head to head competitions at the end of the spring semester. There are approximately six lectures per semester and weekly group meetings with the instructor. The project involves vehicle design, real-time feedback control and trajectory generation, microprocessor design and implementation, wireless communication, computer vision, and artificial intelligence.

**M&AE 565 Biomechanical Systems—Analysis and Design (also BMEP 565)**

Fall. 3 or 4 credits. Prerequisites: undergraduate courses in dynamics and strength of materials, (e.g., T&AM/ENGRD 202 and 203) and senior standing, graduate standing, or permission of instructor.

Mechanics and design in musculoskeletal systems. Emphasis on the modeling and analysis of bones and joints and the analysis and design of bone-implant systems for fracture fixation and joint replacement. Selected topics from the study of the human musculoskeletal system as a mechanical system. Emphasis on the modeling and analysis of bones and joints, and the analysis and design of biomechanical systems frequently encountered in orthopaedic engineering, including bone-implant systems.

**M&AE 570 Finite Element Analysis for Mechanical and Aerospace Design (also M&AE 470)**

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Evening examinations. Term project.

Graduate version of M&AE 470. For description, see M&AE 470. Co-meets with M&AE 470.

**M&AE 571 Applied Dynamics**

Fall. 3 credits. Prerequisites: graduate standing, seniors with T&AM/ENGRD 203, M&AE 326 or permission of instructor. Two 75-minute lectures each week.

Introduction to multibody dynamics; dynamics of rigid bodies; Newton-Euler methods, Lagrangian dynamics, principle of virtual power (Kane-Jourdain methods); and applications to robotics, space dynamics of satellites, electro-mechanical systems. Introduction to multibody simulation using working model.

**M&AE 577 Engineering Vibrations**

Spring. 3 credits. Prerequisite: M&AE 326 or equivalent, graduate standing, or permission of instructor. Graduate version of M&AE 477.

For description, see M&AE 477.

**M&AE 578 Feedback Control Systems**

Fall. 4 credits. Graduate version of M&AE 478.

For description, see M&AE 478.

**M&AE 579 Modeling and Simulation of Mechanical and Aerospace Systems**

Fall. 3 credits. Prerequisite: graduate standing or permission of instructor. Limited enrollment. Evening examinations. Term project. Graduate version of M&AE 479.

For description, see M&AE 479.

**[M&AE 615 Mechanics of Materials: Experiments and Simulations**

Fall. 4 credits. Prerequisite: M&AE 680 (finite elements) or permission of instructor. Not offered 2004–2005.

This course focuses on experiments and simulations related to the mechanical properties of materials and materials processing. A general introduction to sensors and instrumentation for engineering measurements is also included. Testing for mechanical properties/model parameter characterization and simple boundary value problems: linear elasticity, inelastic deformation, fatigue, and fracture, including rate and temperature effects. Process simulation experiments including forging, extrusion, rolling, and ironing may also be conducted. In addition, an emphasis is placed on the experiment/simulation interface. Students perform analyses including finite element modeling to correlate and predict materials behaviors observed in the experiments. These analyses include linear elasticity behavior, state variable plasticity modeling, and fracture mechanics.]

**M&AE 655 Composite Materials (also MS&E 655 and T&AM 655)**

Spring. 4 credits.

For description, see T&AM 655.

**[M&AE 663 Advanced Topics in Neuromuscular Biomechanics (also BMEP 663)**

Spring. 3 credits. Permission of instructor only. Offered alternate years. Not offered 2004–2005. F. Valero-Cuevas.

Advanced topics in modeling and simulation of biomechanical systems using mechanics, dynamics, and control principles. Mathematical representation of the functional interactions among neurons, muscles, and skeletal structures. Numerical prediction of force and movement in biological systems, and projects exploring muscle coordination using optimization methods and general-purpose languages (such as Mathematica or MATLAB). Project-based investigation of clinically relevant topics.]

**[M&AE 664 Mechanics of Bone**

Spring. 3 credits. Prequisites: graduate standing or permission of instructor. Offered alternate years. Not offered 2004–2005.

This course focuses on current methods and results in skeletal research, focusing on bone. Topics include skeletal anatomy and physiology, experimental and analytical methods for determination of skeletal behavior, mechanical behavior of bone tissue, and skeletal functional adaptation to mechanics.]

**M&AE 665 Principles of Tissue Engineering (also BMEP 665 and MS&E 665)**

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.

See BMEP 665 for description.

**[M&AE 675 System Identification and Control**

Fall. 3 credits. Prerequisite: M&AE 478/ECE 471/CHEME 472, M&AE 521/ECE 521, or equivalent. Not offered 2004–2005.

Covers the identification of linear uncertain and nonlinear models and their connections to control. Black box methods, such as subspace methods, and model tuning approaches, such as recursive parameter estimation, are presented. Connections to control include the development of model uncertainties and bounds and control approaches consistent with identified models. Current trends in model identification for control are discussed. Other topics, such as hybrid models, are presented given enough time.]

**[M&AE 676 Model-Based Estimation**

Fall. 4 credits. Prerequisites: linear algebra, differential equations, and MATLAB programming. Open to M.S./Ph.D.; others by permission of the instructor. Offered alternate years. Not offered 2004–2005.

This course covers a variety of ways in which models and experimental data can be used to estimate model quantities that are not directly measured. The two main estimation methods that are presented are least-squares estimation for general problems and Kalman filtering for dynamic systems problems. Techniques for linear models are taught as are techniques for nonlinear models. Both theory and application are presented.]

**M&AE 680 Finite Element Analysis (also CEE 676 and T&AM 666)**

Spring. 3 credits. Prerequisites: T&AM 663 and T&AM 610 or equivalent.

Conceptual, theoretical, and practical bases for finite element analysis in engineering, with emphasis on structural, mechanical, and thermal problems. Focuses on the FEM as a method for numerically solving partial differential equations. Topics include: strong and weak problem forms; weighted-residual and variational formulations; formulations for elliptic, parabolic, and hyperbolic problems (Laplace's equation, elasticity, heat conduction, structural dynamics, wave propagation); meshing and error estimation; and various kinds of elements.

**[M&AE 712 Mechanics of Materials with Oriented Microstructures**

Spring. 4 credits. Prerequisites: T&AM 663 and M&AE 680 (or equivalents). Second year standing in MS/Ph.D. program. Offered alternate years. Not offered 2004–2005.

The focus of this course is the evaluation of mechanical properties from knowledge of the material microstructure, with attention to anisotropic elastic and plastic behaviors. Topics include mathematical and mechanics preliminaries; mathematical foundations of orientations, including parameterizations, symmetries, and fibers; construction and sampling of orientation distributions; hypotheses used to link macro and micro length scales; methods for evaluation of effective elastic and plastic moduli; evolution of orientations and orientation distributions with deformation. Applications to polycrystalline solids (metal alloys and minerals), composite materials, biomaterials (soft tissues), and polymers.]

## Energy, Fluids, and Aerospace Engineering

**M&AE 305 Introduction to Aeronautics**
Fall. 3 credits. Prerequisite: T&AM/ENGRD 203; limited to upperclass engineers, others with permission of instructor.
Introduction to aerodynamic design of aircraft. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Calculation of lift and drag for aircraft. Analysis of aerodynamic performance, stability, and control.

**M&AE 306 Spacecraft Engineering**
Spring. 3 credits. Prerequisite: junior or senior M&AE or ECE students or permission of instructor.
Introduction to spacecraft engineering from satellite design through launch to orbital operation. Topics covered include space missions, space environment, orbital mechanics, systems engineering, and satellite design. Most spacecraft subsystems are introduced including rocket theory, attitude determination and control, thermal design, and communications. Earth orbiting and interplanetary satellites are considered. Discussions of current problems and trends in spacecraft operation and development.

**M&AE 400 Components and Systems: Engineering in a Social Context (also S&TS 400)**
Spring. 3 credits. Prerequisites: upperclass standing, 2 years of college physics. Serves as an approved elective but not as a Field Elective in Mechanical Engineering.
This course addresses, at a technical level, broader questions than are normally posed in the traditional engineering or physics curriculum. Through the study of individual cases such as the Strategic Defense Initiative (SDI), the National Missile Defense, supersonic transport, and the automobile and its effect on the environment, we investigate interactions between the scientific, technical, political, economic, and social forces that are involved in the development of engineering systems.

**M&AE 401 Components and Systems: Engineering in a Social Context**
Fall. 4 credits. Prerequisites: M&AE senior standing, 2 years of college physics. Fulfills M&AE senior field design requirement.
For description, see M&AE 400.

**M&AE 423 Intermediate Fluid Dynamics**
Spring. 3 credits. Prerequisite: M&AE 323. Fulfills technical elective requirement for M&AE students.
This course builds on the foundation of M&AE 323. Emphasis is placed on both the fundamental principles and numerical calculation of real flows (both engineering and environmental) using a computational fluid dynamics package. Topics covered include some exact solutions to the Navier-Stokes equations, boundary layers, wakes and jets, separation, convection, stratified and rotating flows, fluid instabilities, and turbulence.

**M&AE 449 Combustion Engines and Fuel Cells**
Spring. 3 credits. Prerequisites: ENGRD 221 and M&AE 323.
Introduction to combustion engines, with emphasis on the application of thermodynamic and fluid-dynamic principles affecting their performance. Chemical equilibrium and kinetics, ideal-cycle analyses, deviations from ideal processes, engine breathing, combustion, knock. Formation and control of undesirable exhaust emissions.

**M&AE 453 Computer-Aided Engineering: Applications to Biomedical Processes (Also BEE 453)**
Spring. 3 credits. Prerequisite: heat and mass transfer (BEE 350, CHEME 324, M&AE 324, or equivalent).
Fulfills technical elective requirement for M&AE students. See BEE 453 for description.

**M&AE 459 Introduction to Controlled Fusion: Principles and Technology (also ECE 484)**
Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics. Intended for seniors and graduate students in Engineering and the physical sciences. Offered alternate years.
For description, see NS&E 484.

**M&AE 501 Future Energy Systems**
Spring. 3 credits. Prerequisites: ENGRD 221 or equivalent, M&AE 323, 324 recommended or equivalents. Open to graduate and upperclass students or approval from instructor.
Critically examines the technology of energy systems that will be acceptable in a world faced with global warming, local pollution, and declining supplies of oil. The focus is on renewable energy sources (wind, solar, biomass), but other non-carbon-emitting sources (nuclear) and lowered-carbon sources (co-generative gas turbine plants, fuel cells) also are studied. Both the devices as well as the overall systems are analyzed.

**M&AE 506 Aerospace Propulsion Systems**
Fall. 3 credits. Prerequisite: M&AE 323 or permission of instructor. Offered alternate years.
Application of thermodynamic and fluid-mechanical principles to design and performance analysis of aerospace propulsion systems. Jet propulsion principles, including gas turbine engines and rockets. Electric propulsion. Future possibilities for improved performance or aerospace propulsion systems.

**M&AE 507 Dynamics of Flight Vehicles**
Spring. 3 credits. Prerequisites: M&AE 305 and M&AE 323, with 326 concurrently or permission of instructor. Offered alternate years.
Introduction to stability and control of atmospheric-flight vehicles. Review of aerodynamic forces and methods for analysis of linear systems. Static stability and control. Small disturbance equations of unsteady motion. Dynamic stability of longitudinal and lateral-directional motions; transient response to control input. MATLAB will be used extensively. At the level of *Flight: Stability and Control* by Nelson.

**M&AE 523 Intermediate Fluid Dynamics with CFD**
Spring. 4 credits. Prerequisites: graduate standing or permission of instructor.
This course is intended for M.Eng. students who wish to take a single fluid dynamics course. Students desiring more intensive treatment should consider M&AE 601 and one or more of M&AE 636, M&AE 736, and M&AE 737. This class co-meets with M&AE 423. In addition to the normal requirements for M&AE 423, this course includes an extensive CFD design project.

**M&AE 543 Combustion Processes**
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.
An introduction to combustion and flame processes, with emphasis on fundamental fluid dynamics, heat and mass transport, and reaction-kinetic processes that govern combustion rates. Topics covered include thermochemistry, kinetics, vessel explosions, laminar premixed and diffusion flames, droplet combustion, and combustion of solids.

**M&AE 601 Foundations of Fluid Dynamics and Aerodynamics**
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
Foundations of fluid mechanics from an advanced viewpoint, including formulation of continuum fluid dynamics; surface phenomena and boundary conditions at interfaces; fundamental kinematic descriptions of fluid flow, tensor analysis, derivation of the Navier-Stokes equations and energy equation for compressible fluids; and sound waves, viscous flows, boundary layers, and potential flows.

**[M&AE 602 Fluid Dynamics at High Reynolds Numbers**
Spring. 4 credits. Prerequisite: M&AE 601. Offered alternate years. Not offered 2004–2005.
Analysis and discussion of a wide range of specific flows and flow regimes characterized by high Reynolds number are provided. Potential flows, conformal transformations, slender-body theory, and Kelvin's impulse are included. Laminar viscous flows are studied, including fully diffused flows, "exact" solutions, and boundary layers. Compressible flows are treated, including propagation and viscous decay of sound and shock waves and their decay, and the method of characteristics for analysis of such problems. Stratified flows, especially gravity and capillary waves, are analyzed. Various stability problems associated with high Reynolds number flows are discussed. Finally, certain low Reynolds number flows associated with creeping motions or with ultra-small scale will be described.]

**[M&AE 608 Physics of Fluids**
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. Not offered 2004–2005.
Behavior of a gas is considered at the microscopic level. Introduction to kinetic theory: velocity distribution, collisions, Boltzmann equation. Quantum theory: postulates of quantum mechanics, internal structure, rigid rotator, harmonic oscillator, one-electron atom. Statistical mechanics: partition functions, relation to thermodynamics, calculations of thermodynamic properties. Chemical rate processes.]

**[M&AE 627 Experimental Methods in Fluid Dynamics**
Spring. 4 credits. Not offered 2004–2005. E. A. Cowen.
For description, see CEE 637.]

**M&AE 631 Turbulence and Turbulent Flows**
Fall. 4 credits. Prerequisite: M&AE 601, graduate standing, or permission of instructor.
Topics include the dynamics of buoyancy and shear-driven turbulence, boundary-free and bounded shear flows, second-order modeling, the statistical description of turbulence, turbulent transport, and spectral dynamics.

**[M&AE 632 Multiphase Turbulence: Particulates, Drops and Polymer Suspensions**

Spring. 4 credits. Prerequisites: M&AE 601, graduate standing, or permission of instructor. Not offered 2004–2005.

The course will cover turbulent transport of suspensions of microstructures: (i) particulates; (ii) drops; and (iii) polymer molecules. Topics include transport properties of individual microstructures, statistical averaging and the closure problem, Euler/Lagrangian methods, multiphase transport equations, direct numerical simulation and large eddy simulation. The course emphasizes fundamental questions concerning modeling of discrete phases by continuum means.]

**[M&AE 636 Elements of Computational Aerodynamics**

Fall. 4 credits. Prerequisites: graduate standing and a graduate-level course in fluid mechanics. Not offered 2004–2005.

Topics relevant to numerical solution of problems in aerodynamics and fluid mechanics. Analysis and application of computational techniques appropriate for solution of inviscid or high Reynolds number fluid flow problems. Course has common lectures with M&AE 736 but is more applications oriented and uses commercial software for all computational exercises.]

**[M&AE 643 Computational Combustion**

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. Not offered 2004–2005. S. B. Pope.

Examines laminar and turbulent flames and the fundamental chemical and transport processes involved. Emphasis is on using computational tools (Chemkin and Fluent) to calculate flame properties, which are compared to experimental data. Topics covered include thermodynamic equilibrium, chemical kinetics, reactor studies, conservation equations, transport properties, laminar premixed and non-premixed flames, turbulent jets, turbulence modeling, and PDF models of non-premixed turbulent combustion. A knowledge of combustion at the level of M&AE 543, Combustion Processes, is useful but not required.]

**[M&AE 645 Turbulent Reactive Flow**

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. Not offered 2004–2005.

Large turbulent reactive flows occur in combustion devices, the chemical process industry, the atmosphere, oceans, and elsewhere. In the last decade, substantial progress has been made in the understanding of these flows, through both experimental and computational approaches. This course focuses on turbulent combustion and describes the different phenomena involved, the basic processes and governing equations, experimental techniques and observations, and a range of modeling approaches. Class meets, on average, twice per week.]

**M&AE 650 Evolutionary Computation and Design Automation (Also COM S 750, CIS 750)**

Fall. 4 credits.

For description, see COM S 750.

**M&AE 651 Conduction and Radiation Heat Transfer**

Fall, weeks 1–7. 2 credits. Prerequisite: graduate standing; undergraduates by permission of instructor.

An intermediate treatment of heat conduction and thermal radiation. Deductions from the first and second laws of thermodynamics. The conductive transport equation. Physical mechanism of thermal conductivity. Steady, transient, and some multidimensional conduction. The radiative transport equation. Surface and gas radiation properties. Radiant exchange between surfaces and volumes. Molecular and particulate scattering. Radiosity and volume integral formulations. At the level of, but extends, *Heat Transfer* by Bejan.

**M&AE 652 Convection Heat Transfer**

Fall, weeks 8–14. 2 credits. Prerequisite: graduate standing; undergraduates by permission of instructor.

An intermediate treatment of convection heat transfer. Governing equations developed in integral and differential forms. Boundary layers. Laminar and turbulent flows. Internal and external, forced and free convection. Entropy and system arguments for optimal design. Parameter identification. At the level of, but extends, *Heat Transfer* by Bejan.

**M&AE 714 Computational Sensorics: Information Technologies for Complex Continuum Systems**

Fall. 4 credits. Prerequisites: exposure to computational mathematics. Some background in continuum systems and processes such as fluid flow, thermal transport and/or deformation of materials/structures. N. Zabaras.

Syllabus: examples of industrial control of continuum systems; mathematical preliminaries; finite element approach to partial differential equations; inverse problems and inverse problem solving; optimal control problems; numerical analysis of distributed control problems; reduced-order models for continuum systems; feedback laws for continuum systems; robust control and uncertainty; data mining of continuum systems and models; data compression and transmission techniques; advanced adaptive sensing and actuation of continuum fields.

**[M&AE 733 Stability of Fluid Flow**

Fall, on demand. 4 credits. S-U grades only. Prerequisite: graduate standing or permission of instructor. Not offered 2004–2005.

Basic stability and bifurcation theory in fluid systems. "Open" flow systems: inviscid Kelvin-Helmholtz, Rayleigh-Taylor instability, and capillary instability of liquid jets. Stability of parallel shear flows and of concentrated vortex flows. Spatial development of linearly unstable motion: "absolute" and "convective" instability. Thermal, double-diffusive, and related instabilities. Post-bifurcation behavior: the Ginzburg-Landau (Stewartson-Stuart) and Davey-Hocking-Stewartson amplitude equations. Phase dynamics and pattern formation. Stability of periodic motion: Floquet theory. Secondary instabilities; Eckhaus instability, Busse "balloons." Energy stability theory. Effects of symmetry. Taylor-Couette instability.]

**M&AE 734 Analysis of Turbulent Flows**

Spring. 4 credits. Prerequisite: M&AE 601 or permission of instructor. Offered alternate years.

Study of methods for calculating the properties of turbulent flows. Characteristics of turbulent flows. Direct numerical simulations and the closure problem. Reynolds-stress equation: effects of dissipation, anisotropy, deformation. Transported scalars. Probability density functions (pdf's): transport equations, relationship to second-order closures, stochastic modeling, and the Langevin equation. Large-eddy simulations: filtered and residual motions, Smagorinsky, and dynamic models. The course emphasizes comparison of theory with experiment.

**[M&AE 736 Theory of Computational Aerodynamics**

Fall. 4 credits. Prerequisites: graduate standing, an advanced course in continuum mechanics or fluid mechanics, and some higher-level (e.g., FORTRAN, MATLAB) programming experience. Not offered 2004–2005.

Numerical methods to solve inviscid and high-Reynolds-number fluid-dynamics problems, including finite-difference, finite-volume, and surface-singularity methods. Accuracy, convergence, and stability; treatment of boundary conditions and grid generation. Focus on hyperbolic (unsteady flow with shock waves) and mixed hyperbolic-elliptic (steady transonic flow) problems. Assignments require programming a digital computer.]

**M&AE 737 Computational Fluid Mechanics and Heat Transfer**

Fall. 4 credits. Prerequisites: graduate standing; an advanced course in continuum mechanics, heat transfer, or fluid mechanics; and some MATLAB, C++ or other programming experience.

Numerical methods are developed for the elliptic and parabolic partial differential equations that arise in fluid flow and heat transfer when convection and diffusion are present. Finite-difference, finite-volume, and some spectral methods are considered, together with issues of accuracy, stability, convergence, and conservation. Current methods are reviewed. Emphasis is on steady and unsteady essentially incompressible flows. Assigned problems are solved on a digital computer.

## Special Offerings

**M&AE 490 Special Investigations in Mechanical and Aerospace Engineering**

Fall, spring. Credit TBA. Limited to undergraduate students. Prerequisite: permission of instructor.

Intended for an individual student or a small group of students who want to pursue a particular analytical or experimental investigation outside of regular courses or for informal instruction supplementing that given in regular courses.

**M&AE 491 Design Projects in Mechanical and Aerospace Engineering**

Fall, spring. Typically 3 credits. Prerequisite or co-requisite: M&AE 428. Limited to M&AE seniors. Fulfills M&AE senior design requirement.

Intended for individual students or small groups of students who want to pursue particular design projects outside of regular courses. Students should adhere to the design process and documentation guidelines available at the M&AE undergraduate office.

**M&AE 545 Energy Seminar I (also ECE 587, MS&E 545)**
Fall. 1 credit.
For description, see ECE 587.

**M&AE 546 Energy Seminar II (also ECE 588)**
Spring. 1 credit.
For description, see ECE 588.

**M&AE 594 Enterprise Engineering Colloquium (also OR&IE 893–894)**
Fall, spring. 1 credit (usually S-U) each term.
For description, see OR&IE 893–894.

**M&AE 690 Special Investigations in Mechanical and Aerospace Engineering**
Fall, spring. Credit TBA. Limited to graduate students.

**M&AE 695 Special Topics in Mechanical and Aerospace Engineering**
Fall, spring. Credit TBA. Graduate standing and permission of instructor.
Special lectures by faculty members on topics of current research.

**M&AE 791 Mechanical and Aerospace Research Conference**
Fall, spring. 1 credit each term. S-U grades only. For graduate students involved in research projects.
Presentations on research in progress by faculty and students.

**M&AE 799 Mechanical and Aerospace Engineering Colloquium**
Fall, spring. 1 credit each term. Credit limited to graduate students. All students and staff invited to attend.
Lectures by visiting scientists and Cornell faculty and staff members on research topics of current interest in mechanical and aerospace science, especially in connection with new research.

**M&AE 890 Research in Mechanical and Aerospace Engineering**
Credit TBA. Prerequisite: candidacy for M.S. degree in mechanical or aerospace engineering or approval of director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

**M&AE 990 Research in Mechanical and Aerospace Engineering**
Credit TBA. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval of director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

## NUCLEAR SCIENCE AND ENGINEERING

Faculty members in the graduate Field of Nuclear Science and Engineering who are most directly concerned with the curriculum include K. B. Cady, D. A. Hammer, R. W. Kay, and V. O. Kostroun.

**NS&E 484 Introduction to Controlled Fusion: Principles and Technology (also A&EP 484, ECE 484, and M&AE 459)**
Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students.
D. A. Hammer.
Introduction to the physical principles and various engineering aspects underlying power generation by controlled fusion. Topics include fuels and conditions required for fusion power, and basic fusion-reactor concepts; fundamental aspects of plasma physics relevant to fusion plasmas, and basic engineering problems for a fusion reactor; and an engineering analysis of proposed magnetic and/or intertial confinement fusion-reactor designs.

**NS&E 545 Energy Seminar (also ECE 587 and M&AE 545)**
Fall, spring. 1 credit. May be taken for credit both semesters. D. A. Hammer.
For description, see ECE 587.

**NS&E 590 Independent Study**
Fall, spring. 1–4 credits. Grade option letter or S-U. Staff.
Independent study or project under guidance of a faculty member.

**NS&E 591 Project**
Fall, spring. 1–6 credits. Staff.
Master of Engineering or other project under guidance of a faculty member.

## OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

J. Renegar, director; T. Apanasovich, A. Berndt, L. J. Billera, R. G. Bland, J. R. Callister, M. J. Eisner, E. Friedman, X. Guo, S. Henderson, P. L. Jackson, R. A. Jarrow, A. Lewis, W. L. Maxwell, J. A. Muckstadt, N. Prabhu, P. Protter, S. I. Resnick, R. Roundy, D. Ruppert, P. Rusmevichientong, G. Samorodnitsky, D. Shmoys, É. Tardos, M. J. Todd, H. Topaloglu, L. E. Trotter, Jr., B. W. Turnbull, D. P. Williamson

**OR&IE 310 Industrial Systems Analysis**
Spring. 4 credits. Prerequisite or corequisite: ENGRD 270 or permission of instructor. J. Callister.
Design of production facilities, including engineering economy, materials handling, process design, and facility layout. Covers operations analysis, including process scheduling, process evaluation, procedural analysis, project management, methods analysis and design, work measurement, inventory control, job evaluation, and quality engineering and control.

**OR&IE 311 Information Systems and Analysis**
Spring. 4 credits. Three lectures plus recitation. P. Rusmevichientong.
This course presents a systematic and hierarchical approach to the development of information systems, featuring business case justification, requirements analysis, use case analysis, functional analysis, structural design, object-oriented modeling, database design, verification and validation, and project schedule estimation. Graphical tools of analysis (e.g., the Unified Modeling Language) are emphasized. Examples are drawn from business and industrial processes. An integrative design project resulting in a detailed information system design specification (but not necessarily implementation) is required.

**OR&IE 320 Optimization I**
Fall. 4 credits. Prerequisite: MATH 221 or 294. J. Renegar.
Formulation of linear programming problems and solutions by the simplex method. Related topics such as sensitivity analysis, duality, and network programming. Applications include such models as resource allocation and production planning. Introduction to interior-point methods for linear programming.

**OR&IE 321 Optimization II**
Spring. 4 credits. Prerequisite: OR&IE 320 or equivalent. L. Trotter.
A variety of optimization methods stressing extensions of linear programming and its applications but also including topics drawn from integer programming, dynamic programming, and network optimization. Formulation and modeling are stressed as well as numerous applications.

**OR&IE 350 Financial and Managerial Accounting**
Fall. 4 credits. J. Callister.
Course covers principles of accounting, financial reports, financial-transactions analysis, financial-statement analysis, budgeting, job-order and process-cost systems, standard costing and variance analysis, and economic analysis of short-term decisions.

**OR&IE 360 Engineering Probability and Statistics II**
Fall. 4 credits. Prerequisite: ENGRD 270 or equivalent. Staff.
This second course in probability and statistics provides a rigorous foundation in theory combined with the methods for modeling, analyzing, and controlling randomness in engineering problems. Probabilistic ideas are used to construct models for engineering problems, and statistical methods are used to test and estimate parameters for these models. Specific topics include random variables, probability distributions, density functions, expectation and variance, multidimensional random variables, and important distributions including normal, Poisson, exponential, hypothesis testing, confidence intervals, and point estimation using maximum likelihood and the method of moments.

**OR&IE 361 Introductory Engineering Stochastic Processes I**
Spring. 4 credits. Prerequisite: OR&IE 360 or equivalent. Staff.
Basic concepts and techniques of random processes are used to construct models for a variety of problems of practical interest. Topics include the Poisson process, Markov chains, renewal theory, models for queuing, and reliability.

**OR&IE 416 Design of Manufacturing Systems**
Fall. 4 credits. Senior OR&IE students only. Others by permission of instructor only.
P. Jackson, J. Muckstadt.
This is a project course in which students, working in teams, design a manufacturing logistics system and conduct capacity, material flow, and cost analysis of their design. Meetings between project teams and faculty advisers are substituted for some lectures. Analytical methods for controlling inventories, planning production, and evaluating system performance are presented in lectures.

**[OR&IE 431 Discrete Models**
Fall. 4 credits. Prerequisites: OR&IE 320 and COM S 211 or permission of instructor. Not offered 2004–2005.

Course covers basic concepts of graphs, networks, and discrete optimization. Fundamental models and applications, and algorithmic techniques for their analysis. Specific optimization models studied include flows in networks, the traveling salesman problem, and network design.]

**[OR&IE 432 Nonlinear Optimization**

Fall. 4 credits. Prerequisite: OR&IE 320. Not offered 2004–2005.

This course is an introduction to the practical and theoretical aspects of nonlinear optimization. Attention is given to the computational efficiency of algorithms and the application of nonlinear techniques to linear programming; e.g., interior-point methods. Methods of numerical linear algebra are introduced as needed.]

**[OR&IE 434 Optimization Modeling**

Spring. 3 credits. Prerequisites: a grade of at least B- in OR&IE 321/521. Not offered 2004–2005.

Emphasis is on modeling complicated decision problems as linear programs, integer programs, or highly structured nonlinear programs. Besides modeling, students are required to assimilate articles from the professional literature and to master relevant software.]

**OR&IE 435 Introduction to Game Theory**

Fall. 4 credits. Prerequisite: OR&IE 320. M. Todd.

A broad survey of the mathematical theory of games, including such topics as two-person matrix and bimatrix games; cooperative and noncooperative n-person games; and games in extensive, normal, and characteristic function form. Economic market games. Applications to weighted voting and cost allocation.

**OR&IE 436 A Mathematical Examination of Fair Representation**

Spring. 3 credits. Prerequisites: MATH 222 or 294 or permission of instructor. R. Bland.

This course covers the mathematical aspects of the political problem of fair apportionment. The most recognizable form (in the United States) of apportionment is the determination of the number of seats in the U.S. House of Representatives awarded to each state. The constitution indicates that the apportionment should reflect the relative populations, but it does not prescribe a specific method. At first blush it appears that there is a straightforward approach that must lead to a fair, or fairest apportionment, for any fixed house size and known populations. However, indivisibility of seats leads us to interesting mathematical questions and a long, rich, and fractious political history involving many famous figures. The basic ideas extend beyond apportionment of legislatures (in both federal systems and proportional representation systems) to some other realms where indivisible resources are to be allocated among competing constituencies.

**OR&IE 451 Economic Analysis of Engineering Systems**

Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.

Course topics include financial planning, including cash-flow analysis and inventory flow models; engineering economic analysis, including discounted cash flows and taxation effects; application of optimization techniques, as in equipment replacement or capacity expansion models, and issues in designing manufacturing systems. Includes a student group project.

**OR&IE 452 Entrepreneurship for Engineers (also M&AE 461 and ENGRG 461)**

Fall. 3 credits. Enrollment open to upperclass engineers, others by permission of instructor. J. Callister.

For description see M&AE 461.

**[OR&IE 462 Introductory Engineering Stochastic Processes II**

Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Not offered 2004–2005.

Course topics include stationary processes, martingales, random walks, and gambler's ruin problems, processes with stationary independent increments, Brownian motion and other cases, branching processes, renewal and Markov-renewal processes, reliability theory, Markov decision processes, optimal stopping, statistical inference from stochastic models, and stochastic comparison methods for probability models. Applications to population growth, spread of epidemics, and other models.]

**[OR&IE 464 Extreme Value Analysis with Applications to Finance and Data Communications**

Spring. 3 credits. Prerequisites: open to undergraduate and M.Eng. students who have had a stochastic processes course at the level of OR&IE 361 as well as a prior course in statistics. Not offered 2004–2005. S. Resnick.

The course will cover the basic models of extreme events used in hydrology, finance, insurance, environmental science (pollution controls), reliability, risk management.

The basic models contain parameters that must be estimated, and graphical and analytic estimation methods are discussed. Extreme quantiles and very small excedence probabilities need to be estimated, and usually the part of a distribution tail which is way beyond the range of the data needs to be considered. This leads to discussion of estimation needed for VAR (value-at-risk) calculations. The course material intersects the related field of heavy tailed modeling and the implications of heavy tails in insurance and data networks.]

**OR&IE 467 Credit Risk: Modeling, Valuation, and Management**

Spring. 4 credits. Prerequisite: OR&IE 361. K. Giesecke.

Credit risk refers to losses due to changes in the credit quality of a counter party in a financial contract. The course is an introduction to the modeling and valuation of credit risks. Emphasis will be on credit derivative instruments used for hedging credit risks, including credit swaps, spread options, and collateralized debt obligations.

**OR&IE 468 Financial Engineering with Stochastic Calculus I**

Fall. 4 credits. Prerequisite: knowledge of probability at the level of OR&IE 360. X. Guo.

This course is an introduction to continuous-time models of financial engineering and the mathematical tools required to use them, starting with the Black-Scholes model. Driven by the problem of derivative security pricing and hedging in this model, the course develops a practical knowledge of stochastic calculus from an elementary standpoint, covering topics including Brownian motion, martingales, the Ito formula, the Feynman-Kac formula, and Girsanov transformations.

**[OR&IE 469 Financial Engineering with Stochastic Calculus II**

Spring. 4 credits. Prerequisite: OR&IE 468/568. Not offered 2004–2005.

Building on the foundation established in OR&IE 468/568, this course presents no-arbitrage theories of complete markets, including models for equities, foreign exchange, and fixed-income securities, in relation to the main problems of financial engineering: pricing and hedging of derivative securities, portfolio optimization, and risk management. Other topics include model calibration and incomplete markets.]

**OR&IE 473 Operations Research Tools for Financial Engineering.**

Spring. 3 credits. Prerequisites: engineering math through MATH 294 and OR&IE 270 and 360. S. Resnick.

This course is an introduction to the applications of OR techniques, e.g., probability, statistics, and optimization, to finance and financial engineering. No previous knowledge of finance is required. The course first reviews probability and statistics and then surveys assets returns, ARIMA time series models, portfolio selection, regression, CAPM, option pricing, GARCH models, fixed-income securities, resampling techniques, and behavioral finance. The use of MATLAB, MINITAB, and SAS for computation is also covered.

**OR&IE 474 Statistical Data Mining I**

Fall. 3 credits. Prerequisites: OR&IE 360 and MATH 294 or equivalent; or permission of instructor. A. Berdt.

This course examines the statistical aspects of data mining, the effective analysis of large data sets. The first half of the course covers the process of building and interpreting statistical models in a variety of settings including multiple regression and logistic regression. The second half connects these ideas to techniques being developed to handle the large data sets that are now routinely encountered in scientific and business applications. Assignments are done using one or more statistical computing packages.

**OR&IE 476 Applied Linear Statistical Models**

Spring; weeks 1–7. 2 credits. Prerequisite: ENGRD 270. T. Apanasovich.

Course topics include multiple linear regression, diagnostics, model selection, inference, one and two factor analysis of variance. Theory and applications both treated. Use of MINITAB stressed.

**OR&IE 480 Information Technology**

Fall. 4 credits. Pre- or corequisites: COM S/ENGRD 211, plus either OR&IE 310 or OR&IE 350. E. Friedman.

This is a project course that encompasses various aspects of information technology related to operations research and industrial engineering. Topics include the design of databases and information systems, the World Wide Web, the economics and industrial organization of IT goods and services, electronic markets, and agent based interactions.

**OR&IE 481 Delivering OR Solutions with Information Technology**

Spring. 2 credits. Prerequisites: OR&IE 480. Enrollment limited. Staff.

Study of ways information technology is used to deliver operations research methodology in real applications, including decision support systems, embedded operations research techniques, packaged software, and web-based techniques. Several actual applications are investigated. Labs introduce Visual Basic for Applications (VBA) for decision support.

**OR&IE 483 Applications of Operations Research and Game Theory to Information Technology**

Spring. 3 credits. Prerequisites: OR&IE 321, OR&IE 361 or permission of instructor. D. Shmoys.

This course covers a variety of operations research and game theoretic problems arising in information technology. Examples include web searching, network routing and congestion control, online auctions, and trust and reputations in electronic interactions.

**OR&IE 490 Teaching in OR&IE**

Fall, spring. Varying credit. Prerequisite: permission of instructor.

This course involves working as a TA in an OR&IE course. The course instructor assigns credits (the guideline is 1 credit per 4 hours/week of work with a limit of 3 credits).

**OR&IE 499 OR&IE Project**

Fall, spring. Varying credit. Prerequisite: permission of instructor.

Project-type work, under faculty supervision, on a real problem existing in some firm or institution. Opportunities in the course may be discussed with the associate director.

**OR&IE 512 Applied Systems Engineering I (also CEE 504, COM S 504, ECE 512, M&AE 591)**

Fall. 3 credits. Prerequisite: permission of instructor. R. Roundy.

For description, SYSEN 510.

**OR&IE 513 Applied Systems Engineering II (also CEE 505, COM S 505, ECE 513, M&AE 592)**

Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 592, or OR&IE 512). P. Jackson.

For description, see SYSEN 520.

**OR&IE 515 Design of Manufacturing Systems**

Fall. 4 credits. Prerequisite: permission of instructor. Limited to graduate students in Engineering and the Business School.

For description, see OR&IE 416.

**OR&IE 516 Case Studies**

Fall. 1 credit. Limited to M.Eng. students in OR&IE. M. Eisner.

Students are presented with an unstructured problem that resembles a real-world situation. They work in project groups to formulate mathematical models, perform computer analyses of the data and models, and present oral and written reports.

**OR&IE 518 Supply Chain Management**

Spring. 3 credits. Prerequisites: one of the following: OR&IE 310, OR&IE 416, OR&IE 525, or OR&IE 562. J. Muckstadt.

A supply chain is the scope of activities that convert raw materials (e.g., wheat) to finished products delivered to the end consumer (e.g., a box of cereal at the local P&C), usually spanning several corporations. Supply chain management focuses on the flow of products, information, and money through the supply chain. An overview of issues, opportunities, tools, and approaches. Emphasis is on business processes, system dynamics, control, design, re-engineering. Covers the relationship between the supply chain and the company's strategic position relative to its clients and its competition. Considers dimensions of inter-corporate relationships with partners, including decision-making, incentives, and risk.

**OR&IE 520 Operations Research I: Optimization I**

For description, see OR&IE 320.

**OR&IE 521 Optimization II**

For description, see OR&IE 321.

**OR&IE 522 Operations Research I: Topics in Linear Optimization**

Fall. 1 credit. Pre- or corequisite: OR&IE 520. Students who have already taken OR&IE 321 or 521 should not enroll. Limited to M.Eng. students in OR&IE.

An extension of OR&IE 520 that deals with applications and methodologies of dynamic programming, integer programming, and large-scale linear programming.

**OR&IE 523 Operations Research II: Introduction to Stochastic Processes I**

For description, see OR&IE 361.

**[OR&IE 524 Design of Manufacturing Systems II**

Spring; weeks 8–14. 2 credits. Prerequisites: OR&IE 562, OR&IE 416; or by permission of instructor. Not offered 2004–2005.

This project course focuses on the design and analysis of a global corporation's operations. Working in teams, students examine issues pertaining to a prototype company on the following topics: information system design, marketing, strategy, location of facilities, organization design, manufacturing capacity, planning logistics, production planning, scheduling, inventory control, and financial analysis. Meetings between project teams and faculty are substituted for some lectures or laboratories. Analytical methods appropriate for conducting analysis are discussed in lectures.]

**OR&IE 525 Production Planning and Scheduling Theory and Practice**

Fall. 4 credits. Corequisite: OR&IE 320, OR&IE 360. P. Rusmevichientong.

Topics covered include production planning, including MRP, linear programming, and related concepts. Scheduling and sequencing work in manufacturing systems. Job release strategies and control of work in process inventories. Focus is on setup time as a determinant of plans and schedules.

**OR&IE 528–529 Selected Topics in Applied Operations Research**

Fall, spring. Varying credit. Prerequisite: permission of instructor.

Current topics dealing with applications of operations research.

**OR&IE 533 Heuristic Methods for Optimization (also CEE 509, COMS 572, CIS 572)**

Fall. 3 or 4 credits. Prerequisite: graduate standing or COM S/ENGRD 211, 321 or CEE/ENGRD 241 or permission of instructors.

For description, see CEE 509.

**OR&IE 551 Economic Analysis of Engineering Systems**

Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.

Lectures concurrent with OR&IE 451. For description see OR&IE 451.

**OR&IE 560 Engineering Probability and Statistics II**

For description, see OR&IE 360.

**[OR&IE 561 Queuing Systems: Theory and Applications**

Fall. 3 credits. Prerequisite: OR&IE 361 or permission of instructor. Not offered 2004–2005.

Course covers: basic queueing models; delay and loss systems; finite source, finite capacity, balking, reneging; systems in series and in parallel; FCFS versus LCFS; busy period problems; output; design and control problems; priority systems; queueing networks; the product formula; time sharing; server vacations; and applications to equipment maintenance, computer operations and flexible manufacturing systems.]

**OR&IE 562 Inventory Management**

Spring. 3 credits. Prerequisite: OR&IE 321, 361, or permission of instructor. R. Roundy.

The first portion of this course is devoted to the analysis of several deterministic and probabilistic models for the control of single and multiple items at one of many locations. The second portion of this course is presented in an experiential learning format. The focus is on analyzing and designing an integrated production and distribution system for a global company. Applications are stressed throughout.

**[OR&IE 563 Applied Time-Series Analysis**

Fall. 3 credits. Prerequisites: OR&IE 361 and ENGRD 270 or permission of instructor. Not offered 2004–2005.

The first part of this course treats regression methods to model seasonal and nonseasonal data. After that, Box-Jenkins models, which are versatile, widely used, and applicable to nonstationary and seasonal time series, are covered in detail. The various stages of model identification, estimation, diagnostic checking, and forecasting are treated. Analysis of real data is carried out. Assignments require computer work with a time-series package.]

**[OR&IE 564 Introductory Engineering Stochastic Processes II**

Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Lectures concurrent with OR&IE 462.

For description, see OR&IE 462.]

**OR&IE 565 Applied Financial Engineering**

Spring. 4 credits. Limited to M.Eng. students. A. Berndt, K. Giesecke.

This course has two components: a sequence of lectures and a project. The course is co-listed with the Johnson School. The lectures are given by the faculty for the course and by invited speakers from the financial industry. The project satisfies the M.Eng. project requirement.

**[OR&IE 566 Extreme Value Analysis with Applications to Finance and Data Communications**

Spring. 3 credits. S. Resnick.

For description, see OR&IE 464.]

**OR&IE 567 Credit Risk: Modeling, Valuation, and Management**
Spring. 4 credits. Prerequisite: OR&IE 361. K. Giesecke.
For description, see OR&IE 467.

**[OR&IE 569 Financial Engineering with Stochastic Calculus II**
Spring. 4 credits. Prerequisite: OR&IE 468. Not offered 2004–2005.
For description, see OR&IE 469.]

**[OR&IE 574 Statistical Data Mining II**
Spring. 3 credits. Prerequisites: OR&IE 360 and 474, MATH 294. Not offered 2004–2005.
This course is a continuation of OR&IE 474 and covers more advanced techniques such as clustering with applications to market segmentation, discriminant analysis, artificial neural networks, support vector machines, additive models, radial basis function and spline models, principal components, model assessment and selection, bagging, and boosting. Applications to business problems such as quantitative marketing and credit scoring are presented.]

**OR&IE 575 Experimental Design**
Spring; weeks 8–14 (alternates with 576). 2 credits. Prerequisite: OR&IE 476.
Course covers: randomization, blocking, sample size determination, factorial designs, 2^p full and fractional factorials, response surfaces, Latin squares, split plots, and Taguchi designs. Engineering applications. Computing in MINITAB or SAS.

**[OR&IE 576 Regression**
Spring; weeks 8–14 (alternates with 575). 2 credits. Prerequisite: OR&IE 476. Not offered 2004–2005.
Course covers nonlinear regression, advanced diagnostics for multiple linear regression, collinearity, ridge regression, logistic regression, nonparametric estimation including spline and kernel methods, and regression with correlated errors. Computing in MINITAB or SAS.]

**[OR&IE 577 Quality Control**
Fall. 3 credits. Prerequisite: ENGRD 270. Not offered 2004–2005. B. Turnbull.
Course covers concepts and methods for process and acceptance control; control charts for variables and attributes; process capability analysis; acceptance sampling; continuous sampling plans; life tests; and use of experimental design and Taguchi methods for off-line control.]

**OR&IE 580 Simulation Modeling and Analysis**
Fall. 4 credits. Prerequisite: OR&IE 360 (may be taken concurrently) and computing experience, or permission of instructor. H. Topalglu.
Introduction to Monte Carlo and discrete-event simulation. Emphasis on tools and techniques needed in practice. Random variate generation, input and output analysis, modeling using a discrete-event simulation package.

**OR&IE 597 Systems Engineering Project**
Fall; R grade only; spring, 8 credits. For M.Eng. students.
For M. Eng. Students enrolled in the Systems Engineering Option. A substantial, group-based design project that has a strong systems design component. The project must be approved by an ASE 1 instructor before the student enrolls in the course. (The following projects are pre-approved: FSAE, HEV, Robocup, Brain.) A formal report is required.

**OR&IE 598 Master of Engineering Manufacturing Project**
Fall. R grade only; spring, 5 credits. For M.Eng. students.
Project course for M.Eng. students enrolled in the Manufacturing Option coordinated by the Center for Manufacturing Enterprise.

**OR&IE 599 Project**
Fall. R grade only; spring, 5 credits. For M.Eng. students.
Identification, analysis, design, and evaluation of feasible solutions to some applied problem in the OR&IE field. A formal report and oral defense of the approach and solution are required.

**[OR&IE 625 Scheduling Theory**
Spring. 3 credits. Not offered 2004–2005. D. Shmoys.
Scheduling and sequencing problems, including single-machine problems, parallel-machine scheduling, and shop scheduling. The emphasis is on the design and analysis of polynomial time optimization and approximation algorithms and on related complexity issues.]

**OR&IE 626 Advanced Production and Inventory Planning**
Spring. 4 credits. H. Topaloglu.
Introduction to a variety of production and inventory control planning problems, the development of mathematical models corresponding to these problems, and a study of approaches for finding solutions.

**OR&IE 629 Foundations of Game Theory and Mechanism Design for Engineering Applications**
Spring. 3 credits. This class will not assume any prior knowledge of game theory or computer networks, but will assume a basic knowledge of operations research at the level of OR&IE 630 and OR&IE 650. E. Friedman.
This course provides a rigorous foundation for the applications of mechanism design and game theory to problems in engineering such as data networks and computer science. The goal is to develop a deep understanding of the fundamental issues that are important in many applications while presenting many current open research problems.

**OR&IE 630 Mathematical Programming I**
Fall. 4 credits. Prerequisites: advanced calculus and elementary linear algebra. D. Shmoys.
A rigorous treatment of the theory and computational techniques of linear programming and its extensions, including formulation, duality theory, algorithms; sensitivity analysis; network flow problems and algorithms; theory of polyhedral convex sets, systems of linear equations and inequalities, Farkas' Lemma; and exploiting special structure in the simplex method and computational implementation.

**OR&IE 631 Mathematical Programming II**
Spring. 4 credits. Prerequisite: OR&IE 630. M. Todd.
A continuation of OR&IE 630. Introduction to nonlinear programming, interior-point methods for linear programming, complexity theory, and integer programming. Includes some discussion of dynamic programming and elementary polyhedral theory.

**OR&IE 632 Nonlinear Programming**
Fall. 3 credits. Prerequisite: OR&IE 630. A. Lewis.
Necessary and sufficient conditions for unconstrained and constrained optima. Topics include the duality theory, computational methods for unconstrained problems (e.g., quasi-Newton algorithms), linearly constrained problems (e.g., active set methods), and nonlinearly constrained problems (e.g., successive quadratic programming, penalty, and barrier methods).

**[OR&IE 633 Graph Theory and Network Flows**
Spring. 3 credits. Prerequisite: permission of instructor. Not offered 2004–2005.
Topics covered include directed and undirected graphs; bipartite graphs; hamilton cycles and Euler tours; connectedness, matching, and coloring; flows in capacity-constrained networks; and maximum flow and minimum cost flow problems.]

**OR&IE 634 Combinatorial Optimization**
Fall. 3 credits. R. Bland.
Topics in combinatorics, graphs, and networks, including matching, matroids, polyhedral combinatorics, and optimization algorithms.

**[OR&IE 635 Interior-Point Methods for Mathematical Programming**
Fall. 3 credits. Prerequisites: MATH 411 and OR&IE 630, or permission of instructor. Not offered 2004–2005.
Interior-point methods for linear, quadratic, and semidefinite programming and, more generally, for convex programming. Discussion of the basic ingredients—barrier functions, central paths, and potential functions—that go into the construction of polynomial-time algorithms and various ways of combining them. Emphasis on recent mathematical theory and the most modern viewpoints.]

**[OR&IE 636 Integer Programming**
Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 2004–2005.
Topics covered include discrete optimization; linear programming in which the variables must assume integral values; theory, algorithms, and applications; and cutting-plane and enumerative methods, with additional topics drawn from recent research in this area.]

**OR&IE 637 Semidefinite Programming**
Spring. 2 credits. Pre- or corequisite: OR&IE 635. M. Todd.
Course covers: linear optimization over the cone of positive semidefinite symmetric matrices; applications to control theory, eigenvalue optimization, and strong relaxations of combinatorial optimization problems; duality; computational methods, particularly interior-point algorithms.

**[OR&IE 639 Polyhedral Convexity**
Spring. 3 credits. Prerequisite: basic knowledge of linear algebra. Not offered 2004–2005.
A comprehensive introduction to the geometry and combinatorics of polyhedral convex sets. Also, linear inequalities, supporting and separating hyperplanes; polarity; convex hulls, facets, and vertices; face lattices; convex cones and polytopes; minkowski sums; gale transforms; simplicial and polyhedral subdivision; and applications to linear programming, combinatorial optimization, and computational geometry.]

**OR&IE 650 Applied Stochastic Processes**
Fall. 4 credits. Prerequisite: a 1-semester calculus-based probability course. X. Guo.
An introduction to stochastic processes that presents the basic theory together with a variety of applications. Topics include Markov processes, renewal theory, random walks, branching processes, Brownian motion, stationary processes, martingales, and point processes.

**OR&IE 651 Probability**
Spring. 4 credits. Prerequisite: real analysis at the level of MATH 413 and a previous 1-semester course in calculus-based probability. G. Samorodnitsky.
Course covers sample spaces, events, sigma fields, probability measures, set induction, independence, random variables, expectation, review of important distributions and transformation techniques, convergence concepts, laws of large numbers and asymptotic normality, and conditioning.

**[OR&IE 662 Advanced Stochastic Processes**
Fall. 3 credits. Prerequisite: OR&IE 651 or equivalent. Not offered 2004–2005.
Course topics include Brownian motion, martingales, Markov processes, and topics selected from: diffusions, stationary processes, point processes, weak convergence for stochastic processes and applications to diffusion approximations, Lévy processes, regenerative phenomena, random walks, and stochastic integrals.]

**OR&IE 665 Storage and Data Communication Models**
Fall. 3 credits. U. Prabhu.
This course covers a selection of topics including queues, storage, insurance risk, dams, and data communication. The basic assumptions of the underlying models are discussed with emphasis on their common features. The overall objective is the study of the stochastic processes that arise from these models. The approach is based on the fluctuation theory of random walks, Levy processes, and Markov-additive processes. Further topics for discussion include stochastic comparisons and statistical inference from the models with particular emphasis on data communication models. Current research on network models with discrete and fluid inputs is discussed.

**OR&IE 670 Statistical Principles**
Fall. 4 credits. Corequisite: OR&IE 650 or equivalent. T. Apanasovich.
Topics include review of distribution theory of special interest in statistics: normal, chi-square, binomial, Poisson, t, and F; introduction to statistical decision theory; sufficient statistics; theory of minimum variance unbiased point estimation; maximum likelihood and Bayes estimation; basic principles of hypothesis testing, including Neyman-Pearson Lemma and likelihood ratio principle; confidence interval construction; and introduction to linear models.

**[OR&IE 671 Intermediate Applied Statistics**
Fall. 3 credits. Prerequisite: OR&IE 670 or equivalent. Not offered 2004–2005.
Course topics include statistical inference based on the general linear model; least-squares estimators and their optimality properties; likelihood ratio tests and corresponding confidence regions; and simultaneous inference. Applications in regression analysis and ANOVA models. Covers variance components and mixed models. Use of the computer as a tool for statistics is stressed.]

**OR&IE 673 Empirical and Computational Issues in Finance**
Spring. 3 credits. Prerequisites: stochastic processes at the level of OR&IE 650 and statistics at the level of OR&IE 670, or permission of instructor. A. Berndt.
This course is designed to introduce students to existing empirical work in finance and to demonstrate the use of statistical, econometric, and numerical methods in the analysis of financial data. The topics covered include linear and nonlinear time series analysis, high-frequency data and market microstructure, continuous-time models, extreme values and quantile estimation, volatility models, and MCMC methods. Numerous applications using market data are presented. MATLAB programming skills are useful.

**OR&IE 674 Statistical Learning Theory for Data Mining**
Fall. 3 credits. Prerequisites: Probability at the level of OR&IE 651, and statistical at the level of OR&IE 670. D. Ruppert.
This course will provide a thorough grounding in probabilistic and computational methods for statistical data mining. We intend to cover a subset of the following topics from supervised and unsupervised data mining: The framework of learning. Performance measures and model selection. Methodology, theoretical properties and computing algorithms used in parametric and nonparametric methods for regression and classification. Frequentist and Bayesian methods.

**OR&IE 677 Sequential Methods in Statistics**
Spring. 3 credits. S-U grades only. B. Turnbull.
The statistical theory of sequential design and analysis of experiments has many applications; including monitoring data from clinical trials in medical studies and quality control in manufacturing operations. Topics in this course include classical sequential hypothesis tests, Wald's SPRT, stopping rules, Kiefer-Weiss test, optimality, group sequential methods, estimation, repeated confidence intervals, stochastic curtailment, adaptive designs, and Bayesian and decision theoretic approaches.

**[OR&IE 678 Bayesian Statistics and Data Analysis**
Spring. 3 credits. Prerequisites: OR&IE 670 and some knowledge of measure theoretic probability, e.g., co-registration in OR&IE 650. Not offered 2004–2005.
Priors, posteriors, Bayes estimators, Bayes factors, credible regions, hierarchical models, computational methods (especially MCMC), empirical Bayes methods, Bayesian robustness. The course will include data analysis and MCMC computation in WinBUGS and possibly other languages such as MATLAB.]

**[OR&IE 680 Simulation**
Spring. 4 credits. Prerequisite: computing experience and OR&IE 650 or equivalent, or permission of instructor. Not offered 2004–2005.
Introduction to Monte Carlo and discrete-event simulation. Emphasis on underlying theory. Random variate generation, input and output analysis, variance reduction, selection of current research topics.]

**OR&IE 728–729 Selected Topics in Applied Operations Research**
Fall, spring. Credit TBA.
Current research topics dealing with applications of operations research.

**OR&IE 738–739 Selected Topics in Mathematical Programming**
Fall, spring. Credit TBA.
Current research topics in mathematical programming.

**OR&IE 768–769 Selected Topics in Applied Probability**
Fall, spring. Credit TBA.
Topics are chosen from current literature and research areas of the staff.

**OR&IE 778–779 Selected Topics in Applied Statistics**
Fall, spring. Credit TBA.
Topics chosen from current literature and research of the staff.

**OR&IE 790 Special Investigations**
Fall, spring. Credit TBA.
For individuals or small groups. Study of special topics or problems.

**OR&IE 799 Thesis Research**
Fall, spring. Credit TBA.
For individuals doing thesis research for master's or doctoral degrees.

**OR&IE 891 Operations Research Graduate Colloquium**
Fall, spring. 1 credit. Staff.
A weekly 1–1/2 hour meeting devoted to presentations by distinguished visitors, by faculty members, and by advanced graduate students on topics of current research in the field of operations research.

**OR&IE 893–894 Enterprise Engineering Colloquium (also M&AE 594)**
893, fall; 894, spring. 1 credit (usually S-U) each term.
A weekly meeting for Master of Engineering students. Discussion with industry speakers and faculty members on the uses of engineering in the economic design, manufacturing, marketing, and distribution and goods and services.

## SYSTEMS ENGINEERING

P. L. Jackson, director; L. K. Nozick, director of graduate studies; M. Campbell, R. D'Andrea, R. A. Davidson, E. Garcia, A. R. George, J. A. Muckstadt, A. F. Myers, R. O. Roundy, F. B. Schneider, B. Selman, C. A. Shoemaker, J. R. Stedinger, R. J. Thomas, H. Topaloglu, M. A. Turnquist

**SYSEN 510 Applied Systems Engineering (also CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512)**
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. A. R. George, R. Roundy.
Fundamental ideas of systems engineering, and their application to design and development of various types of engineered systems. Defining system requirements, creating effective project teams, mathematical tools for system analysis and control, testing and evaluation, economic considerations, and the system life cycle.

**SYSEN 511 Applied Systems Engineering**
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. Intended for off-campus students. Staff.
For description see SYSEN 510.

**SYSEN 520 System Architecture, Behavior, and Optimization (M&AE 592, CEE 505, COM S 505, ECE 513, OR&IE 513)**
Spring. 3 credits. Prerequisite: Applied System Engineering (M&AE 591, CEE 504, COM S 504, ECE 512, or OR&IE 512, SYSEN 520 or SYSEN 521) or permission of instructor. Staff.
This is an advanced course in the application of the systems engineering process to the design and operation of complex systems. Topics introduced in Applied Systems Engineering I will be covered in greater depth. Topics include techniques for design, simulation, optimization, and control of complex systems. Case studies and system simulations in diverse areas will provide context for the application of these techniques. Students majoring in Systems Engineering enroll in SYSEN 520. Students taking Option in Systems Engineering enroll in M&AE 592, CEE 505, CS 505, EE 513, or OR&IE 513. Students in Continuing Education enroll in SYSEN 521. Lectures are identical for all versions.

**SYSEN 521 System Architecture, Behavior, and Optimization**
Spring. 3 credits. Prerequisites: Applied System Engineering I Fundamentals or permission of instructor. Intended for off-campus students. Staff.
For description see SYSEN 520.

**SYSEN 570 Special Topics in Systems Engineering**
On demand. 1–4 credits. Staff.
Supervised study by individuals or small groups of one or more specialized topics not covered in regular courses.

**SYSEN 571 Practicum in Systems Engineering**
On demand. 3 credits. Staff.
Supervised study by individuals or small groups of one or more specialized topics not covered in regular courses.

**SYSEN 590 Systems Engineering Design Project**
Fall. 6–8 credits. Prerequisites: permission of instructor. Staff.
A design project that incorporates the principles of systems engineering for a complex system. Projects are performed by teams of students working together to meet the requirements of the project.

**SYSEN 680 Topics in Systems Engineering Research**
Fall. 1.5 credits. Staff.
Advanced topics in systems engineering research.

**SYSEN 681 Topics in Systems Engineering Research**
Spring. 1.5 credits. Staff.
Advanced topics in systems engineering research.

# THEORETICAL AND APPLIED MECHANICS

T. J. Healey, chair; J. A. Burns, K. B. Cady, H. D. Conway (Emeritus), E. Cranch (Emeritus), J. M. Guckenheimer, C. Y. Hui, J. T. Jenkins, S. Mukherjee, S. L. Phoenix, R. H. Rand, P. Rosakis, A. L. Ruina, W. H. Sachse, S. Strogatz, Z. J. Wang, A. Zehnder

## Basics in Engineering Mathematics and Mechanics

**T&AM 118 Design Integration: A Portable CD Player (also ENGRI 118 and MS&E 118)**
Spring. 3 credits.
This is a course in the Introduction to Engineering series. For description, see ENGRI 118.

**T&AM 202 Mechanics of Solids (also ENGRD 202)**
Fall, spring. 4 credits Prerequisite: PHYS 112, coregistration in MATH 192, or permission of instructor.
For description, see ENGRD 202.

**T&AM 203 Dynamics (also ENGRD 203)**
Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in MATH 293, or permission of instructor.
For description, see ENGRD 203.

## Engineering Mathematics

**T&AM 190 Calculus for Engineers (also MATH 190)**
Fall. 4 credits. Prerequisite: 3 years of high school mathematics, including trigonometry and logarithms.
For description, see MATH 190.

**T&AM 191 Calculus for Engineers (also MATH 191)**
Fall. 4 credits. Prerequisite: 3 years of high school mathematics, including trigonometry.
For description, see MATH 191.

**T&AM 192 Calculus for Engineers (also MATH 192)**
Fall, spring, or summer. 4 credits. Prerequisite: MATH/T&AM 191.
For description, see MATH 192.

**T&AM 293 Engineering Mathematics (also MATH 293)**
Fall, spring. 4 credits. Prerequisite: MATH/T&AM 192 plus a knowledge of computer programming equivalent to that taught in COM S 100.
For description, see MATH 293.

**T&AM 294 Engineering Mathematics (also MATH 294)**
Fall, spring. 4 credits. Prerequisite: MATH/T&AM 293.
For description, see MATH 294.

**T&AM 310 Advanced Engineering Analysis I**
Fall, spring. 3 credits. Prerequisites: MATH/T&AM 293 and 294.
Course covers: initial value, boundary value, and eigenvalue problems in linear ordinary differential equations. Also covers: special functions, linear partial differential equations. This is an introduction to probability and statistics. Use of computers to solve problems is emphasized.

**T&AM 311/511 Advanced Engineering Analysis II**
Spring. 3 credits. Prerequisite: MATH/T&AM 294 or equivalent (T&AM 311 can be taken without T&AM 310).
Mathematical modeling of physical and biological systems. Examples range from molecular diffusion, bacteria swimmers, chemotaxis, and physiological flows, to bird flight. The mathematics necessary to understand these phenomena is discussed in depth. They include probability theory, PDEs, stability analysis, complex variable analysis, and numerical analysis. Students from all fields are encouraged to take the course.

**T&AM 610 Methods of Applied Mathematics I**
Fall. 3 credits. Intended for beginning graduate students in engineering and science. An intensive course, requiring more time than is normally available to undergraduates (see T&AM 310–311) but open to exceptional undergraduates with permission of instructor.
Emphasis is on applications. Course covers: linear algebra, calculus of several variables, vector analysis, series, ordinary differential equations, and complex variables.

**T&AM 611 Methods of Applied Mathematics II**
Spring. 3 credits. Prerequisite: T&AM 610 or equivalent.
Emphasis is on applications. Course covers: partial differential equations, transform techniques, tensor analysis, calculus of variations.

**T&AM 613 Methods of Applied Mathematics IV**
Spring. 3 credits. Prerequisite: T&AM 610 and 611 or equivalent.
Topics include asymptotic behavior of solutions of linear and nonlinear ODE (e.g., the WKB boundary layer and multiple-scale methods) and symptotic expansion of integrals (method of steepest descent, stationary phase, and Laplace methods). Also covers regular and singular perturbation methods for PDE (e.g., method of composite expansions). Other topics (depending on instructor) may include normal forms, center manifolds, Liapunov-Schmidt reductors, and Stokes phenomenon. The course may also include computer exercises at the option of the instructor.

**[T&AM 614 Methods of Applied Math V**
Spring. 3 credits. Prerequisites: T&AM 610 plus T&AM 611 or equivalent. Not offered 2004–2005.]

**T&AM 617 Mathematical Biofluid Dynamics**
Spring. 3 credits.
Course topics include ciliary propulsion (biology); Eulerian realm: fish swimming, bird flight, etc.; review of potential flows; two-dimensional theory of lunate tails; unsteady airfoil theory; Weisfogh mechanism of insect flight.

## Continuum Mechanics

**T&AM 455 Introduction to Composite Materials (also CEE 475, M&AE 455 and MS&E 555)**
Spring. 3 credits.
Course topics include introduction to composite materials; varieties and properties of fiber reinforcements and matrix materials; micromechanics of stiffness and stress transfer

in discontinuous fiber/matrix arrays; orthotropic elasticity as applied to parallel fibers in a matrix and lamina; theory of stiffness (tension, bending, torsion) and failure of laminates and composite plates, including computer software for design; and manufacturing methods and applications for composities. There is a group component design and manufacturing paper required, and a group laboratory on laminated component fabrication.

**T&AM 591 Master of Engineering Design Project I**
Fall. 3–10 credits.
M. Eng. (Mechanics) project related to the Master of Engineering Mechanics.

**T&AM 592 Master of Engineering Design Project I**
Spring. 3–10 credits.
M. Eng. (Mechanics) project related to the Master of Engineering Mechanics.

**T&AM 655 Composite Materials (also M&AE 655 and MS&E 655)**
Spring. 4 credits.
Taught jointly with T&AM 455 using same lecture material, but also includes more advanced material and homework through additional lectures. Additional material includes shear-lag models of stress transfer around arrays of fiber breaks, including viscoelastic effects, statistical theories of composite strength and failure; stress distributions around holes and cuts in composite laminates; and compressive strength of composites. Laboratory on effects of holes and notches in composites.

**T&AM 663 Solid Mechanics I**
Fall. 4 credits.
Rigorous introduction to solid mechanics emphasizing linear elasticity: tensors; deformations, rotations and strains; balance principles; stress; small-strain theory; linear elasticity, anisotropic and isotropic; basic theorems of elastostatics; and boundary-value problems, e.g., plates, St. Venant's solutions.

**T&AM 664 Solid Mechanics II**
Spring. 4 credits. Prerequisites: MATH 610 and T&AM 663 or equivalent.
Preparation for advanced courses in solid mechanics. Topics include singular solutions in linear elasticity; plane stress, plane strain, anti-plane shear, airy stress functions; linear viscoelasticity; cracks and dislocations; classical plasticity; thermoelasticity; and three-dimensional elasticity.

**T&AM 666 Finite Element Analysis (also M&AE 680 and CEE 772)**
Spring. 3 credits. Prerequisites: T&AM 663 or equivalent.
For description, see M&AE 680.

**T&AM 751 Continuum Mechanics and Thermodynamics**
Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents.
Course topics include kinematics; conservation laws; the entropy inequality; constitutive relations: frame indifference, material symmetry; and finite elasticity, rate-dependent materials, and materials with internal state variables.

## Dynamics and Space Mechanics

**T&AM 570 Intermediate Dynamics**
Fall. 3 credits.
Course topics include Newtonian mechanics; motion in rotating coordinate systems; introduction to analytical mechanics; virtual work, Lagrangian mechanics; Hamilton's principle; small vibration and stability theory. Newtonian-Eulerian mechanics of rigid bodies; and gyroscopes.

**T&AM 578 Nonlinear Dynamics and Chaos**
Spring. 3 credits. Prerequisite: MATH/ T&AM 293 or equivalent.
Introduction to nonlinear dynamics, with applications to physics, engineering, biology, and chemistry. Emphasizes analytical methods, concrete examples, and geometric thinking. Topics: one-dimensional systems; bifurcations; phase plane; nonlinear oscillators; and Lorenz equations, chaos, strange attractors, fractals, iterated mappings, period doubling, renormalization.

**T&AM 672 Celestial Mechanics (also ASTRO 579)**
Spring. 3 credits. Offered alternate years.
Course topics include description of orbits; 2-body, 3-body, and n-body problems; Hill curves, libration points and their stability; capture problems; osculating orbital elements, perturbation equations; effects of gravitational potentials, atmospheric drag, and solar radiation forces on satellite orbits; and secular perturbations, resonances, mechanics of planetary rings.

**T&AM 675 Nonlinear Vibrations**
Spring. 3 credits. Prerequisite: T&AM 578 or equivalent. Offered alternate years.
Quantitative analysis of weakly nonlinear systems in free and forced vibrations, perturbation methods, averaging method. Applications to problems in mechanics, physics, and biology. Additional topics may include Hopf bifurcation, Invariant manifolds, coupled oscillators, vibrations in continuous media, normal forms, and exploitation of symmetry.

**T&AM 776 Applied Dynamical Systems (also MATH 717)**
For description, see MATH 717.

## Special Courses, Projects, and Thesis Research

**T&AM 491–492 Project in Engineering Science**
Fall, 491; spring, 492. 1–4 credits, as arranged.
Projects for undergraduates under the guidance of a faculty member.

**T&AM 796–800 Topics in Theoretical and Applied Mechanics**
Fall, spring. 1–3 credits, as arranged.
Special lectures or seminars on subjects of current interest. Topics are announced when the course is offered.

**T&AM 890 Master's Degree Research in Theoretical and Applied Mechanics**
Fall, spring. 1–15 credits, as arranged. S-U grades optional.
Thesis or independent research at the M.S. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

**T&AM 990 Doctoral Research in Theoretical and Applied Mechanics**
Fall, spring. 1–15 credits, as arranged. S-U grades optional.
Thesis or independent research at the Ph.D. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

# FACULTY ROSTER

Abel, John F., Ph.D., U. of California at Berkeley. Prof., Civil and Environmental Engineering
Ahner, Beth A., Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Biological and Environmental Engineering
Albonesi, David H., Ph.D., U. of Massachusetts. Assoc. Prof., Electrical and Computer Engineering
Albright, Louis D., Ph.D., Cornell U. Prof., Biological and Environmental Engineering
Allmendinger, Richard, Ph.D., Stanford U. Prof., Earth and Atmospheric Sciences
Aneshansley, Daniel J., Ph.D., Cornell U. Prof., Biological and Environmental Engineering
Anton, A. Brad, Ph.D., California Inst. of Technology. Assoc. Prof., Chemical and Biomolecular Engineering
Apanasovich, Tatiyana, Ph.D., Texas A&M U. Asst. Prof., Operations Research and Industrial Engineering
Apsel, Alyssa B., Ph.D., Johns Hopkins U. Clare Boothe Luce Assistant Professor of Electrical and Computer Engineering
Aquino, Wilkens, Ph.D., U. of Illinois. Asst. Prof., Civil and Environmental Engineering
Archer, Lynden A., Ph.D., Stanford U. Assoc. Prof., Chemical and Biomolecular Engineering
Arms, William, Ph.D., U. of Sussex. Prof., Computer Science
Ast, Dieter G., Ph.D., Cornell U. Prof., Materials Science and Engineering
Avedisian, C. Thomas, Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering
Baeumner, Antje J., Ph.D., Universitat Stuttgart. Asst. Prof., Biological and Environmental Engineering
Bailey, Graeme, Ph.D., U. of Birmingham. Prof., Computer Science
Baker, Shefford P., Ph.D., Stanford U. Assoc. Prof., Materials Science and Engineering
Bala, Kavita, Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Computer Science
Ballantyne, Joseph M., Ph.D., Massachusetts Inst. of Technology. Prof., Electrical and Computer Engineering
Barazangi, Muawia, Ph.D., Columbia U. Prof., Earth and Atmospheric Sciences
Bartel, Donald L., Ph.D., U. of Iowa. Prof., Mechanical and Aerospace Engineering and Biomedical Engineering
Bartsch, James A., Ph.D., Purdue U. Assoc. Prof., Biological and Environmental Engineering
Bassett, William A., Ph.D., Columbia U. Prof. (Emeritus), Earth and Atmospheric Sciences
Berger, Toby, Ph.D., Harvard U. Irwin and Joan Jacobs Professor of Engineering, Electrical and Computer Engineering
Berndt, Antje, Ph.D., Stanford U. Asst. Prof., Operations Research and Industrial Engineering
Bird, John M., Ph.D., Rensselaer Polytechnic Institute. Prof. (Emeritus), Earth and Atmospheric Sciences
Birman, Kenneth P., Ph.D., U. of California at Berkeley. Prof., Computer Science
Bisogni, James J., Ph.D., Cornell U. Assoc. Prof., Civil and Environmental Engineering
Blakely, John M., Ph.D., Glasgow U. (Scotland). Herbert Fisk Johnson Professor of Engineering, Materials Science and Engineering
Bland, Robert G., Ph.D., Cornell U. Prof., Operations Research and Industrial Engineering

Bloom, Arthur L., Ph.D., Yale U. Prof. (Emeritus), Earth and Atmospheric Sciences
Bojanczyk, Adam W., Ph.D., U. of Warsaw (Poland). Assoc. Prof., Electrical and Computer Engineering
Bonassar, Lawrence J., Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Mechanical and Aerospace Engineering and Biomedical Engineering
Booker, John F., Ph.D., Cornell U. Graduate School Prof. (Emeritus), Mechanical and Aerospace Engineering
Brock, Joel D., Ph.D., Massachusetts Inst. of Technology. Director and Prof., Applied and Engineering Physics
Brown, Larry D., Ph.D., Cornell U. Prof., Earth and Atmospheric Sciences
Brutsaert, Wilfried H., Ph.D., U. of California at Davis. William L. Lewis Prof. of Engineering, Civil and Environmental Engineering
Buhrman, Robert A., Ph.D., Cornell U. John Edson Sweet Professor of Engineering, Applied and Engineering Physics
Burns, Joseph A., Ph.D., Cornell U. Irving Porter Church Professor of Engineering, Theoretical and Applied Mechanics; Astronomy
Burtscher, Martin, Ph.D., U. of Colorado at Boulder. Asst. Prof., Electrical and Computer Engineering
Cady, K. Bingham, Ph.D., Massachusetts Inst. of Technology. Prof., Theoretical and Applied Mechanics; Nuclear Science and Engineering
Callister, John R., Ph.D., Cornell U. Kinzelberg Director of Entrepreneurship in Engineering
Campbell, Mark E., Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Mechanical and Aerospace Egineering
Cardie, Claire T., Ph.D. U. of Massachusetts at Amherst. Assoc. Prof., Computer Science
Caruana, Richard, Ph.D., Carnegie Mellon U. Asst. Prof., Computer Science
Cathles, Lawrence M. III, Ph.D., Princeton U. Prof., Earth and Atmospheric Sciences
Caughey, David A., Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering
Chiang, Hsiao-Dong, Ph.D., U. of California at Berkeley. Prof., Electrical and Computer Engineering
Cisne, John L., Ph.D., U. of Chicago. Prof., Earth and Atmospheric Sciences
Clancy, Paulette, Ph.D., Oxford U. (England). Prof., Chemical and Biomolecular Engineering
Cohen, Claude, Ph.D., Princeton U. Prof., Chemical and Biomolecular Engineering
Coleman, Thomas F., Ph.D., U. of Waterloo. Prof., Computer Science
Collins, Lance R., Ph.D., U. of Pennsylvania. Prof., Mechanical and Aerospace Engineering
Colucci, Stephen J., Ph.D., SUNY Albany. Prof., Earth and Atmospheric Sciences
Constable, Robert L., Ph.D., U. of Wisconsin. Prof., Computer Science
Conway, Harry D., Ph.D., London U. Prof. Emeritus, Theoretical and Applied Mechanics
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